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VENTCF2: AN ALGORITHM AND ASSOCIATED FORTRAN 77 SUBROUTINE FOR CALCULATING FLOW THROUGH A HORIZONTAL CEILING/FLOOR VENT IN A ZONE-TYPE COMPARTMENT FIRE MODEL

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ABSTRACT

An algorithm and associated FORTRAN 77 subroutine, called *VENTCF2*, is presented for calculating the effects on two-layer compartment fire environments of the quasi-steady flow through a circular, shallow (i.e., small ratio of depth to diameter), horizontal vent connecting two spaces. The two spaces can be either two inside rooms of a multi-room facility or one inside room and the outside ambient environment local to the vent. The description of the flow through the vent is determined by combining considerations of the uni-directional-type of flow driven by a cross-vent pressure difference and, when appropriate, the combined pressure- and buoyancy-driven flows which occur when the density configuration across the vent is unstable, i.e., a relatively cool, dense gas in the upper space overlays a less dense gas in the lower space. In the algorithm, calculation of the rates of flow exchange between the two spaces is based on previously reported model equations. Characteristics of the geometry and the instantaneous environments of the two spaces are assumed to be known and specified as inputs. The outputs calculated by the algorithm/subroutine are the rates and the properties of the vent flow at the elevation of the vent as it enters the top space from the bottom space and/or as it enters the bottom space from the top space. Rates of mass, enthalpy, and products of combustion extracted by the vent flows from upper and lower layers of inside room environments and from outside ambient spaces are determined explicitly. *VENTCF2* is an advanced version of the algorithm/subroutine *VENTCF* in that it includes an improved theoretical and experimental basis. The subroutine is completely modular and it is suitable for general use in two-layer, multi-room, zone-type fire model computer codes. It has been tested over a wide range of input variables and these tests are described.

Keywords: **building fires; compartment fires; computer models; fire models; fire research; mathematical models; vents; zone models**

INTRODUCTION

This work presents an algorithm and associated FORTRAN 77 subroutine, called *VENTCF2*, to calculate under arbitrary conditions the instantaneous effects on two-layer fire environments of the quasi-steady flow through a horizontal vent connecting two spaces involved in a compartment fire. The subroutine is designed to be modular and easy to integrate into any two-layer zone-type compartment fire model. The algorithm *VENTCF2*, which was developed in [2], is based on ideas outlined in [1], theoretical considerations of [3], and experimental data from reduced-scale hot-air/cool-air experiments of [4] and salt-water/fresh-water experiments of [5] and [6]. *VENTCF2* is an advanced version of the algorithm/subroutine *VENTCF* [1, 7] which was developed without benefit of [3]-[5].

Flow through horizontal vents is a general problem associated with ventilation of enclosed, heated/cooled spaces. It is a problem whose general solution is required, for example, if one is to be able to predict the spread of smoke (i.e., fire-heated and -contaminated air) and the flow of fresh air (i.e., oxygen, which could sustain a fire, lack of which could extinguish a fire) during fires in multi-room facilities. Reference here is to smoke spread between contiguous rooms, or between a smoky room and the outside environment, separated by a horizontal partition (i.e., ceiling/floor) with penetrations (i.e., vents), where room-to-room or room-to-outside, cross-vent, pressure differences of arbitrary magnitude and direction can be generated by forced-ventilation HVAC systems, thermal buoyancy forces (i.e., stack effect), and/or wind effects. The problem has application in fire scenarios involving top-vented atria, stairwells, ship holds, etc. The purpose for this work is to provide a computational tool that can be used to predict these phenomena.

THE BASIC PROBLEM

Consider the flow through a horizontal ceiling/floor vent connecting two spaces, one on top of the other, involved in a fire-generated environment. The two spaces can be two inside rooms of a multi-room facility, as depicted in Figure 1a of APPENDIX A (page VENTCF2 - 15), or they can be comprised of one inside room of a facility and one outside space, either above or below the room, which is used to simulate conditions, local to the vent, of the outside ambient. The latter configurations are depicted in Figures 1b and 1c of APPENDIX A, respectively.

When the upper gas is less dense than the lower gas, i.e., the fluid configuration is stable, the flow through the vent is determined by a traditional orifice-type flow model. Then, flow is determined by the cross-vent pressure difference without any regard for buoyancy effects (see, e.g., References [8] and [9]). When the configuration is unstable and the upper gas is more dense than the lower gas, the effects of combined pressure and buoyancy forces can be significant. For example if the cross-vent pressure is relatively small, less than the critical value, Δp_{FLOOD}, the unstable density configuration leads to an exchange-type of flow, with gas in the lower space rising into the upper space and gas from the upper space dropping into the lower space, where the flow rate from the high- to the low-pressure side of the vent is the larger of the two. Even when the cross-vent pressure difference is large enough to produce uni-directional flow, the effect of buoyancy can be great enough to reduce significantly the flow rate from what it would be in the absence of a cross-vent density difference. In the present algorithm, for the case of unstable configurations the calculation of the flow between the two spaces is based on the analysis of [2], which uses theoretical considerations of [3], and experimental data of [4] (hot-air/cool-air in the uni-directional flow regime, flow from top to bottom) and of [5] and [6] (salt-water/fresh/water vent flows in the exchange-flow regime).

The algorithm/subroutine *VENTCF2* would be used to calculate the net instantaneous rates of addition of mass, enthalpy, and products of combustion of interest and the properties of the vent flows to each of the two connected spaces at the elevation of the vent. A determination of where such flows go once they enter the receiving spaces would be determined with the use of additional algorithms and associated subroutines. These additional algorithms, which would use the output of the present algorithm/subroutine, would be based on considerations beyond the scope of the present work.

A flow through the horizontal vent which enters one of the spaces joined by the vent is extracted from the other space. Depending on the configuration of the two spaces, the direction of the flow, and, in the case of inside rooms, the elevation of the two-layer interface (i.e., at the floor, ceiling, or in-between), the present algorithm determines explicitly the rates of extraction of mass, enthalpy, and products of combustion from the upper and lower layers of the one or two inside rooms and/or from an outside ambient space joined by the vent under consideration. Along with other components of flow to or from the layers of the inside rooms, determined with the use of other algorithms, these rates would be used to continue in time the solution to the equations of the overall fire model. These are the equations used to simulate mathematically the facility's overall dynamic fire environment.

LIMITATIONS ON VENT SHAPE

For unstable density configurations, the model of [2] and, therefore, the algorithm/subroutine presented here is for flow through a circular, shallow (i.e., small ratio of depth-to-diameter), horizontal vent. It is expected that the model will give reasonable estimates of flow even for non-circular vents, provided the aspect ratio (maximum-to-minimum span) of a vent shape of interest is not too much different than unity. Indeed, one of the example calculations of [2], which includes comparisons with some relevant experimental data, provides limited support for the applicability of the model in the case of square vents. However, when cross-vent pressure differences are small-to-moderate compared to Δp_{FLOOD}, use of the model for high-aspect-ratio and/or moderate-to-large-depth vents is not valid. Results beyond those developed in [2] are required before the present work can be evaluated for its use in predicting flows through the latter types of vent shapes.

THE ALGORITHMS AND ASSOCIATED FORTRAN 77 SUBROUTINES *VENTCF2* AND *VENTCF2A* FOR CALCULATING THE EFFECTS OF FLOW THROUGH HORIZONTAL CEILING/FLOOR VENTS

The algorithm *VENTCF2* and a listing of its associated subroutine, coded in FORTRAN 77, is presented in APPENDIX A. This is a stand-alone document that can be inserted as a new entry into the catalog of modular algorithms and associated FORTRAN 77 subroutines of [10]. APPENDIX B includes stand-alone documentation and the associated subroutine for *VENTCF2A*, a modification of *VENTCF2*. *VENTCF2A* provides special considerations for "smoothing" rates of layer extraction from the flow source room at times of relatively thin adjacent-vent layers. When used in a full zone model, and depending on the integration software for the particular model, the considerations in *VENTCF2A* eliminate singularities that may cause convergence problems in fire simulations at times when adjacent-vent layers are growing or shrinking from near-zero depths.

Reference [10] is a catalog of algorithms/subroutines useful for simulating the physical phenomena in multi-room zone-type compartment fire model computer codes. Pagination of the two documents of the present APPENDIXES A and B, and of all entries of the Reference [10] catalog is according to name of the particular algorithm/subroutine (in this case, *VENTCF2* and *VENTCF2A*) and page number of the catalog entry.

The catalog of [10] was conceived of as a growing document where the entries would be available for general use by people interested in: developing or improving, for their own particular needs, a general or special-purpose multi-room zone-type compartment fire model; or predicting isolated compartment fire phenomena, for whatever reason.

The development, technology transfer, and use of a Reference-[10]-type of catalog of algorithms and associated subroutines is enhanced by maintaining guidelines for a uniform format of algorithm/subroutine documentation. In this regard a prototype format was developed and used in all Reference-[10] algorithm/subroutine catalog entries. This format, which is followed here, includes the following elements:

TITLE	-	Should indicate the main purpose of the algorithm/subroutine.
DESCRIPTION	-	General description of the algorithm.
OUTPUT	-	List of output variables, including definitions and units.
INPUT	-	List of input variables, including definitions and units.
CALCULATIONS	-	Concise description of the rules for obtaining the output variables from the input variables. This would include or refer explicitly to all equations required in the calculation. If other algorithms/subroutines are required, then these should be readily available and referenced.
SUBROUTINES USED	-	Listing of or explicit reference to each algorithm/subroutine used to carry out the calculations.
REFERENCES	-	A list of references.
SUBROUTINE VARIABLES	-	cross-reference of all nomenclature (including units) introduced in the above sections to the nomenclature used in the FORTRAN 77 subroutine.
PREPARED BY	-	Names of those who prepared the algorithm/subroutine and date of preparation.
SUBROUTINE	-	Listing of the subroutine. This would be well-commented and would include a summary of the purpose of the subroutine and definitions (including units) of its input and output variables.

TESTING THE SUBROUTINES

Subroutine *VENTCF2*

Extensive parametric testing of the subroutine *VENTCF2* has been carried out. A wide range of environment scenarios were considered for each of the three basic configurations of Figure 1 of *VENTCF2* (page VENTCF2 - 15 of the APPENDIX A). For each configuration, parameters were varied in a manner as to simulate all possible combinations of the following:

a. for the two layers of an inside space: the usual case with two non-zero-thickness layers (i.e., layer interface between the ceiling and the floor), or one non-zero-thickness layer and one zero-thickness layer (i.e., layer interface at the ceiling or floor);

b. stable or unstable cross-vent density configuration;

c. the reference elevation for an outside space is above, at, or below the vent elevation;

d. 1.0 atmosphere reference pressure, $p_{REF,1}$, in the top space (i.e., $p_{DAT} = 101325Pa$ with $\delta p_{REF,1} \equiv p_{REF,1} - p_{DAT} = 0$) with reference pressure in the bottom space, $p_{REF,2}$, varying from 0.01 atmospheres to 2.0 atmospheres (i.e., $-0.99p_{DAT} < \delta p_{REF,2} \leq p_{DAT}$); and

e. 1.0 atmosphere reference pressure, $p_{REF,2}$, in the bottom space (i.e., $p_{DAT} = 101325Pa$ with $\delta p_{REF,2} \equiv p_{REF,2} - p_{DAT} = 0$) with reference pressure in the top space, $p_{REF,1}$, varying from 0.01 atmospheres to 2.0 atmospheres (i.e., $-0.99p_{DAT} < \delta p_{REF,1} \leq p_{DAT}$)

Five distinct elevations (relative to a datum elevation), y_N, N = 1 to 5, and three distinct densities, ρ_N, N = 1 to 3, were required to construct the environment scenarios. These were chosen to be:

$$y_1 = 0.0m; \ y_2 = 1.5m; y_3 = 3.0m; \ y_4 = 4.5m; \ y_5 = 6.0m \qquad (1)$$
$$\rho_1 = 1.00kg/m^3; \ \rho_2 = 0.50kg/m^3; \ \rho_3 = 0.25kg/m^3$$

When the environment of an inside room involved two layers, the layer densities were specified to be in a stable configuration (i.e., a low density layer above a high density layer).

All scenarios involve an example vent of area $A_V = 1m^2$.

Table 1 identifies all configurations and environment specifications that were used in the parametric testing of the subroutine. This involved 162 basic Cases. Each Case involved a separate parametric study of over two thousand calls to the subroutine. These covered the above pressure range of either condition d. or condition e. The calls involved incremental changes of the relative reference pressures, $\delta p_{REF,1}$ for condition e and $\delta p_{REF,2}$ for condition d, which were small enough to reveal details of the exchange-flow phenomena, these being sensitive to fractional-pascal-level variations in cross-vent pressure differences.

For each Case, Table 1 identifies values of the parameters which define the configuration of the two spaces, as illustrated in Figure 1 of *VENTCF2*, and the states of the environments in the spaces. These are the parameters used to call the subroutine. (The reader is referred to the NOMENCLATURE Section for explanation of terms used in the table.) Also explicitly identified in the table are those Cases which involve unstable cross-vent density configurations. When cross-vent pressure differences are small enough in magnitude, such Cases lead to the exchange-flow phenomena which are of particular interest.

Presented in Figures 1 and 2 are plots of the calculated mass flow rates to upper room 1, $\dot{M}_{VENT,1}$, and to lower room 2, $\dot{M}_{VENT,2}$, as functions of the computed cross-vent pressure difference, Δp, for Cases 28, 29, and 30. As in Eq. (2) of *VENTCF2*, Δp, an output variable of the subroutine, is defined as

$$\Delta p = p_2 - p_1 \qquad (2)$$

where p_1 and p_2 are the pressures in the top and bottom spaces at the elevation of the vent (see Figure 2 of *VENTCF2*).

As indicated in Table 1, Cases 28, 29, and 30 involve two inside rooms where, as depicted in Figure 1a of VENTCF2, both of these have an upper and a lower layer. Case 28 involves a neutrally-stable cross-vent density configuration since the density immediately above the vent (in the lower layer of room 1), $\rho_{L,1} = \rho_2 = 0.50 kg/m^3$, is identical to the density immediately below the vent (in the upper layer of room 2). Cases 29 and 30 involve an unstable cross-vent density configuration since the density immediately above the vent, $\rho_{L,1} = \rho_1 = 1.0 kg/m^3$, is greater than the density immediately below the vent, $\rho_{U,2} = \rho_2 = 0.50 kg/m^3$.

The scale of the Δp abscissa of Figure 1 is relatively coarse, and the plots reveal the calculated mass flow rates through the vent as a result of large cross-vent pressure differences, i.e., when effects of compressibility become significant as could be the case, for example, for fires in nearly-hermetically-sealed facilities. In the figure, the sharp breaks in the $\dot{M}_{VENT,1}$ and $\dot{M}_{VENT,2}$ plots for Cases 28 and 30 and for Case 29, respectively, correspond to cross-vent pressure differences, Δp, which separate choked from unchoked flow through the vent. Define p_{HIGH} and p_{LOW} as the absolute pressures on the high- and low-pressure side of the vent, respectively. Then, consistent with Eqs. (7)-(15) of *VENTCF2*, such choking occurs for air (i.e., $\gamma = 1.40$) when [9, 11]

$$p_{LOW}/p_{HIGH} \le [2/(\gamma + 1)]^{\gamma/(\gamma - 1)} = 0.528 \tag{3}$$

As indicated in Figure 1, for Case 29 the parameters specified in Table 1 lead to a prediction of choked vent flow from room 1 to room 2 approximately when $\Delta p \le -0.472 p_{DAT} = -0.478(10^5)$Pa. Similarly, for Cases 28 and 30 the parameters specified in Table 1 lead to a prediction of choked vent flow from room 1 to room 2 approximately when $\Delta p \le -0.894 p_{DAT} = -0.906(10^5)$Pa. Also, for Cases 28 and 30, choked flow from room 2 to room 1 is predicted when $\Delta p \ge 0.472 p_{DAT} = 0.478(10^5)$Pa. Finally, for Case 29, choked flow from room 2 to room 1 is predicted when $\Delta p \ge 0.894 p_{DAT} = 0.906(10^5)$Pa.

The scale of the Δp abscissa of Figure 2 is relatively fine, and the plots reveal the calculated mass flow rates through the vent when the cross-vent pressure differences are at or close to zero. Since the Case-28 density configuration is neutrally-stable, i.e., only uni-directional or zero flow is possible, the mass flow rates through the vent corresponding to $\Delta p = 0$ are seen to be identically zero. However, for the unstable cross-vent density configurations of Cases 29 and 30, the vent flow algorithm is seen to lead to the exchange-flow phenomenon. In particular, there is a non-zero vent flow exchange between the top and bottom spaces whenever $|\Delta p| < \Delta p_{FLOOD}$, where Δp_{FLOOD} is defined in Eq. (20) of *VENTCF2*.

Subroutine *VENTCF2A*

The subroutine *VENTCF2A* was found to give plausible results when tested in CCFM.VENTS [10, 12-14] with a variety of time-dependent one- and two-room fire scenarios. Except for the small-scale, limited-regime data of [4-6], which were used to develop *VENTCF2*, the algorithm has not been validated experimentally.

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NOMENCLATURE

A_V	Area of vent
$\dot{M}_{VENT,I}$; I = 1 to 2	Mass flow rate of vent flow component entering space I
p_{DAT}	Datum absolute pressure
p_{HIGH}	Maximum of (p_1, p_2)
p_{LOW}	Minimum of (p_1, p_2)
$p_{REF,I}$; I = 1, 2	Absolute pressure in space I at reference elevation $y_{REF,I}$
p_1 [p_2]	Absolute hydrostatic pressure in top [bottom] space at vent elevation
y_C, y_L, y_R for space I	$y_{CEIL,I}$, $y_{LAYER,I}$, and $y_{REF,I}$, respectively
$y_{CEIL,I}$ [$y_{REF,I}$]; I = 1, 2	If space I is inside room: elevation of ceiling [floor] of room I above datum elevation; if space I is "outside room": $y_{CEIL,I}$ and $y_{REF,I}$ are identical and equal to reference elevation of space I above datum elevation, i.e., $y_{CEIL,I} \equiv y_{REF,I}$
$y_{LAYER,I}$; I = 1, 2	If space I is inside room: elevation of upper/lower layer interface in room I above datum elevation; if space I is "outside room": $y_{LAYER,I} \equiv y_{REF,I}$
y_{VENT}	Elevation of vent above datum elevation
Δp	$p_2 - p_1$
Δp_{FLOOD}	Minimum value of $\lvert\Delta p\rvert$, in cases of unstable cross-vent density configurations, leading to uni-directional vent flow; Eq. (20) of APPENDIX A
$\Delta p_{FLOOD,I}$; I = 1, 2	Δp_{FLOOD} for onset of uni-directional flow into space I
$\delta p_{REF,I}$; I = 1, 2	Pressure at reference elevation, $y_{REF,I}$, in space I above datum absolute pressure, p_{DAT}; if space I is inside room, then $\delta p_{REF,I}$ and $y_{REF,I}$ correspond to pressure and elevation, respectively, within the room and at floor
$\rho_{L,I}$ [$\rho_{U,I}$]; I = 1, 2	If space I is inside room: density of lower [upper] layer in room I if volume of lower [upper] layer is non-zero (if lower [upper] layer volume is zero then $\rho_{L,I}$ [$\rho_{U,I}$] is not used in calculation); if space I is "outside room": $\rho_{L,I}$ is uniform density there and $\rho_{U,I} \equiv \rho_{L,I}$

TABLE 1: **Configurations/Environments Used to Test the VENTCF2 Subroutine**

$\rho_1 = 1.00 kg/m^3 > \rho_2 = 0.50 kg/m^3 > \rho_3 = 0.25 kg/m^3$
$y_1 = 0.0m < y_2 = 1.5m < y_3 = 3.0m < y_4 = 4.5m < y_5 = 6.0m$
$p_{DAT} = 1.01325(10^5)Pa$; $A_V = 1m^2$

CASES 1-54: **SPACE 1 (TOP SPACE) IS INSIDE ROOM, SPACE 2 (BOTTOM SPACE) IS INSIDE ROOM - FIGURE 1a of APPENDIX A**

CASE NO.		SPACE 1	SPACE 2		
		Lower Layer $y_R=y_3$ $y_L=y_5$ $y_C=y_5$	Lower Layer $y_R=y_1$ $y_L=y_3$ $y_C=y_3$		
1				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
2				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
3				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
4				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
5	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
6	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Two Layers $y_R=y_1$ $y_L=y_2$ $y_C=y_3$		
7				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
8				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
9				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
10				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
11	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
12	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Upper Layer $y_R=y_1$ $y_L=y_1$ $y_C=y_3$		
13				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
14				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
15				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
16				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
17	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
18	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$

* Unstable cross-vent density configuration

TABLE 1: (Cont'd) **Configurations/Environments Used to Test the VENTCF2 Subroutine**

$\rho_1 = 1.00kg/m^3 > \rho_2 = 0.50kg/m^3 > \rho_3 = 0.25kg/m^3$
$y_1 = 0.0m < y_2 = 1.5m < y_3 = 3.0m < y_4 = 4.5m < y_5 = 6.0m$
$p_{DAT} = 1.01325(10^5)Pa;\ A_V = 1m^2$

CASES 1-54: (CONT'D) **SPACE 1 (TOP SPACE) IS INSIDE ROOM, SPACE 2 (BOTTOM SPACE) IS INSIDE ROOM - FIGURE 1a of APPENDIX A**

CASE NO.		SPACE 1	SPACE 2		
		Two Layer $y_R=y_3$ $y_L=y_4$ $y_C=y_5$	Lower Layer $y_R=y_1$ $y_L=y_3$ $y_C=y_3$		
19				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
20				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
21				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
22				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
23	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
24	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Two Layers $y_R=y_1$ $y_L=y_2$ $y_C=y_3$		
25				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
26				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
27				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
28				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
29	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
30	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Upper Layer $y_R=y_1$ $y_L=y_1$ $y_C=y_3$		
31				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
32				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
33				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
34				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
35	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
36	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$

* Unstable cross-vent density configuration

TABLE 1: (Cont'd) Configurations/Environments Used to Test the VENTCF2 Subroutine

$\rho_1 = 1.00\text{kg/m}^3 > \rho_2 = 0.50\text{kg/m}^3 > \rho_3 = 0.25\text{kg/m}^3$
$y_1 = 0.0\text{m} < y_2 = 1.5\text{m} < y_3 = 3.0\text{m} < y_4 = 4.5\text{m} < y_5 = 6.0\text{m}$
$p_{DAT} = 1.01325(10^5)\text{Pa}; A_V = 1\text{m}^2$

CASES 1-54: (CONT'D) SPACE 1 (TOP SPACE) IS INSIDE ROOM, SPACE 2 (BOTTOM SPACE) IS INSIDE ROOM - FIGURE 1a of APPENDIX A

CASE NO.		SPACE 1	SPACE 2		
		Upper Layer $y_R=y_3$ $y_L=y_3$ $y_C=y_5$	Lower Layer $y_R=y_1$ $y_L=y_3$ $y_C=y_3$		
37				$\rho_{U,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
38				$\rho_{U,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DA}T<\delta p_{REF,1}\le p_{DAT}$
39				$\rho_{U,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
40				$\rho_{U,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
41	*			$\rho_{U,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
42	*			$\rho_{U,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Two Layers $y_R=y_1$ $y_L=y_2$ $y_C=y_3$		
43				$\rho_{U,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
44				$\rho_{U,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
45				$\rho_{U,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
46				$\rho_{U,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
47	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
48	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Upper Layer $y_R=y_1$ $y_L=y_1$ $y_C=y_3$		
49				$\rho_{U,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
50				$\rho_{U,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
51				$\rho_{U,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
52				$\rho_{U,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
53	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
54	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$

* Unstable cross-vent density configuration

TABLE 1: (Cont'd) **Configurations/Environments Used to Test the VENTCF2 Subroutine**

$\rho_1 = 1.00\text{kg/m}^3 > \rho_2 = 0.50\text{kg/m}^3 > \rho_3 = 0.25\text{kg/m}^3$
$y_1 = 0.0\text{m} < y_2 = 1.5\text{m} < y_3 = 3.0\text{m} < y_4 = 4.5\text{m} < y_5 = 6.0\text{m}$
$p_{DAT} = 1.01325(10^5)\text{Pa};\ A_V = 1\text{m}^2$

CASES 55-108: SPACE 1 (TOP SPACE) IS OUTSIDE SPACE, SPACE 2 (BOTTOM SPACE) IS INSIDE ROOM - FIGURE 1b of APPENDIX A

CASE NO.		SPACE 1	SPACE 2		
		All One Layer $y_R=y_4$ $y_L=y_4$ $y_C=y_4$	Lower Layer $y_R=y_1$ $y_L=y_3$ $y_C=y_3$		
55				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
56				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
57				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DA}T<\delta p_{REF,2}\le p_{DAT}$
58				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
59	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
60	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Two Layers $y_R=y_1$ $y_L=y_2$ $y_C=y_3$		
61				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
62				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
63				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
64				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
65	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
66	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Upper Layer $y_R=y_1$ $y_L=y_1$ $y_C=y_3$		
67				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
68				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
69				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
70				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
71	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
72	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$

* Unstable cross-vent density configuration

TABLE 1: (Cont'd) Configurations/Environments Used to Test the VENTCF2 Subroutine

$\rho_1 = 1.00\text{kg/m}^3 > \rho_2 = 0.50\text{kg/m}^3 > \rho_3 = 0.25\text{kg/m}^3$
$y_1 = 0.0\text{m} < y_2 = 1.5\text{m} < y_3 = 3.0\text{m} < y_4 = 4.5\text{m} < y_5 = 6.0\text{m}$
$p_{DAT} = 1.01325(10^5)\text{Pa};\ A_V = 1\text{m}^2$

CASES 55-108: (CONT'D) SPACE 1 (TOP SPACE) IS OUTSIDE SPACE, SPACE 2 (BOTTOM SPACE) IS INSIDE ROOM - FIGURE 1b of APPENDIX A

CASE NO.		SPACE 1	SPACE 2		
		All One Layer $y_R=y_3$ $y_L=y_3$ $y_C=y_3$	Lower Layer $y_R=y_1$ $y_L=y_3$ $y_C=y_3$		
73		↓	↓	$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
74		↓	↓	$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
75		↓	↓	$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
76		↓	↓	$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
77	*	↓	↓	$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
78	*	↓	↓	$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
		↓	Two Layers $y_R=y_1$ $y_L=y_2$ $y_C=y_3$		
79		↓	↓	$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
80		↓	↓	$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
81		↓	↓	$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
82		↓	↓	$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
83	*	↓	↓	$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
84	*	↓	↓	$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
		↓	Upper Layer $y_R=y_1$ $y_L=y_1$ $y_C=y_3$		
85		↓	↓	$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
86		↓	↓	$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
87		↓	↓	$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
88		↓	↓	$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
89	*	↓	↓	$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
90	*	↓	↓	$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$

* Unstable cross-vent density configuration

TABLE 1: (Cont'd) Configurations/Environments Used to Test the VENTCF2 Subroutine

$\rho_1 = 1.00\text{kg/m}^3 > \rho_2 = 0.50\text{kg/m}^3 > \rho_3 = 0.25\text{kg/m}^3$
$y_1 = 0.0\text{m} < y_2 = 1.5\text{m} < y_3 = 3.0\text{m} < y_4 = 4.5\text{m} < y_5 = 6.0\text{m}$
$p_{DAT} = 1.01325(10^5)\text{Pa};\ A_V = 1\text{m}^2$

CASES 55-108: (CONT'D) SPACE 1 (TOP SPACE) IS OUTSIDE SPACE, SPACE 2 (BOTTOM SPACE) IS INSIDE ROOM - FIGURE 1b of APPENDIX A

CASE NO.		SPACE 1	SPACE 2		
		All One Layer $y_R=y_2$ $y_L=y_2$ $y_C=y_2$	Lower Layer $y_R=y_1$ $y_L=y_3$ $y_C=y_3$		
91		↓	↓	$\rho_{U,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
92				$\rho_{U,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DA}T<\delta p_{REF,1}\le p_{DAT}$
93				$\rho_{U,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
94				$\rho_{U,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
95	*			$\rho_{U,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
96	*			$\rho_{U,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Two Layers $y_R=y_1$ $y_L=y_2$ $y_C=y_3$		
97			↓	$\rho_{U,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
98				$\rho_{U,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
99				$\rho_{U,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
100				$\rho_{U,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
101	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
102	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			Upper Layer $y_R=y_1$ $y_L=y_1$ $y_C=y_3$		
103			↓	$\rho_{U,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
104				$\rho_{U,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
105				$\rho_{U,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
106				$\rho_{U,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
107	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
108	*	↓	↓	$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$

* Unstable cross-vent density configuration

TABLE 1: (Cont'd) **Configurations/Environments Used to Test the VENTCF2 Subroutine**

$\rho_1 = 1.00 kg/m^3 > \rho_2 = 0.50 kg/m^3 > \rho_3 = 0.25 kg/m^3$
$y_1 = 0.0m < y_2 = 1.5m < y_3 = 3.0m < y_4 = 4.5m < y_5 = 6.0m$
$p_{DAT} = 1.01325(10^5)Pa;\ A_V = 1m^2$

CASES 109-162: SPACE 1 (TOP SPACE) IS INSIDE ROOM, SPACE 2 (BOTTOM SPACE) IS OUTSIDE SPACE - FIGURE 1c of APPENDIX A

CASE NO.		SPACE 1	SPACE 2		
		Lower Layer	All One Layer		
		$y_R=y_3$ $y_L=y_5$ $y_C=y_5$	$y_R=y_4$ $y_L=y_4$ $y_C=y_4$		
109				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
110				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
111				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
112				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
113	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
114	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			$y_R=y_3$ $y_L=y_3$ $y_C=y_3$		
115				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
116				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
117				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
118				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
119	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
120	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			$y_R=y_2$ $y_L=y_2$ $y_C=y_2$		
121				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
122				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
123				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
124				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
125	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
126	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$

* Unstable cross-vent density configuration

TABLE 1: (Cont'd) Configurations/Environments Used to Test the VENTCF2 Subroutine

$\rho_1 = 1.00 kg/m^3 > \rho_2 = 0.50 kg/m^3 > \rho_3 = 0.25 kg/m^3$
$y_1 = 0.0m < y_2 = 1.5m < y_3 = 3.0m < y_4 = 4.5m < y_5 = 6.0m$
$p_{DAT} = 1.01325(10^5)Pa;\ A_V = 1m^2$

CASES 109-162: (CONT'D) SPACE 1 (TOP SPACE) IS INSIDE ROOM, SPACE 2 (BOTTOM SPACE) IS OUTSIDE SPACE - FIGURE 1c of APPENDIX A

CASE NO.		SPACE 1	SPACE 2		
		Two Layer $y_R=y_3$ $y_L=y_4$ $y_C=y_5$	All One Layer $y_R=y_4$ $y_L=y_4$ $y_C=y_4$		
127				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
128				$\rho_{L,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
129				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
130				$\rho_{L,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
131	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
132	*			$\rho_{L,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
			$y_R=y_3$ $y_L=y_3$ $y_C=y_3$		
133				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
134				$\rho_{L,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
135				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
136				$\rho_{L,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
137	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
138	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
			$y_R=y_2$ $y_L=y_2$ $y_C=y_2$		
139				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
140				$\rho_{L,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
141				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
142				$\rho_{L,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$
143	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\leq p_{DAT}$
144	*			$\rho_{L,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\leq p_{DAT}$

* Unstable cross-vent density configuration

TABLE 1: (Cont'd) **Configurations/Environments Used to Test the VENTCF2 Subroutine**

$\rho_1 = 1.00\text{kg/m}^3 > \rho_2 = 0.50\text{kg/m}^3 > \rho_3 = 0.25\text{kg/m}^3$
$y_1 = 0.0\text{m} < y_2 = 1.5\text{m} < y_3 = 3.0\text{m} < y_4 = 4.5\text{m} < y_5 = 6.0\text{m}$
$p_{DAT} = 1.01325(10^5)\text{Pa};\ A_V = 1\text{m}^2$

CASES 109-162: (CONT'D) **SPACE 1 (TOP SPACE) IS INSIDE ROOM, SPACE 2 (BOTTOM SPACE) IS OUTSIDE SPACE - FIGURE 1c of APPENDIX A**

CASE NO.		SPACE 1	SPACE 2		
		Upper Layer $y_R=y_3$ $y_L=y_3$ $y_C=y_5$	All One Layer $y_R=y_4$ $y_L=y_4$ $y_C=y_4$		
145				$\rho_{U,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
146				$\rho_{U,1}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
147				$\rho_{U,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
148				$\rho_{U,1}=\rho_1=\rho_{L,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
149	*			$\rho_{U,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
150	*			$\rho_{U,1}=\rho_1>\rho_{L,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			$y_R=y_3$ $y_L=y_3$ $y_C=y_3$		
151				$\rho_{U,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
152				$\rho_{U,1}=\rho_3<\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
153				$\rho_{U,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
154				$\rho_{U,1}=\rho_2=\rho_{U,2}<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
155	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
156	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2<\rho_{L,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
			$y_R=y_2$ $y_L=y_2$ $y_C=y_2$		
157				$\rho_{U,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
158				$\rho_{U,1}=\rho_2<\rho_{U,2}=\rho_1$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
159				$\rho_{U,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
160				$\rho_{U,1}=\rho_1=\rho_{U,2}$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$
161	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,1}=0.,-p_{DAT}<\delta p_{REF,2}\le p_{DAT}$
162	*			$\rho_{U,1}=\rho_1>\rho_{U,2}=\rho_2$	$\delta p_{REF,2}=0.,-p_{DAT}<\delta p_{REF,1}\le p_{DAT}$

* Unstable cross-vent density configuration

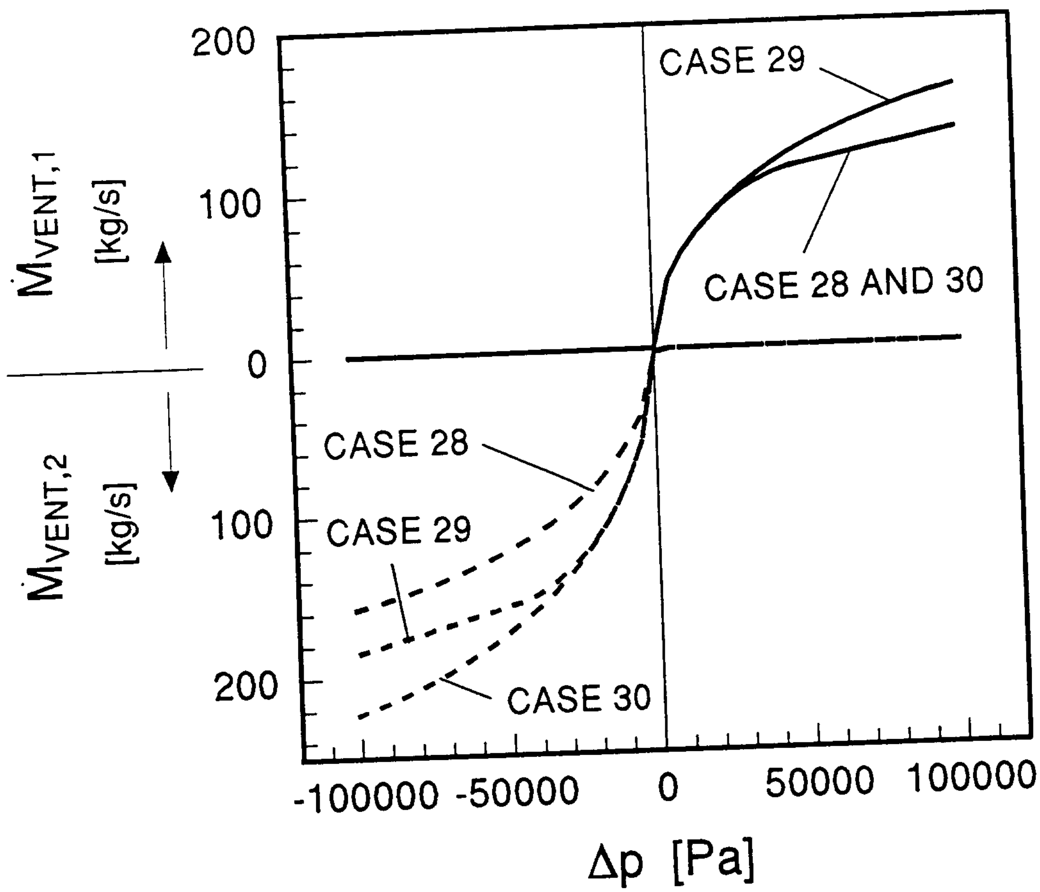

Figure 1. Plots of the calculated mass flow rate to upper space 1, $\dot{M}_{VENT,1}$, and to lower space 2, $\dot{M}_{VENT,2}$, as functions of the computed (coarse-scale) cross-vent pressure difference, Δp, for Cases 28, 29, and 30 (see Table 1).

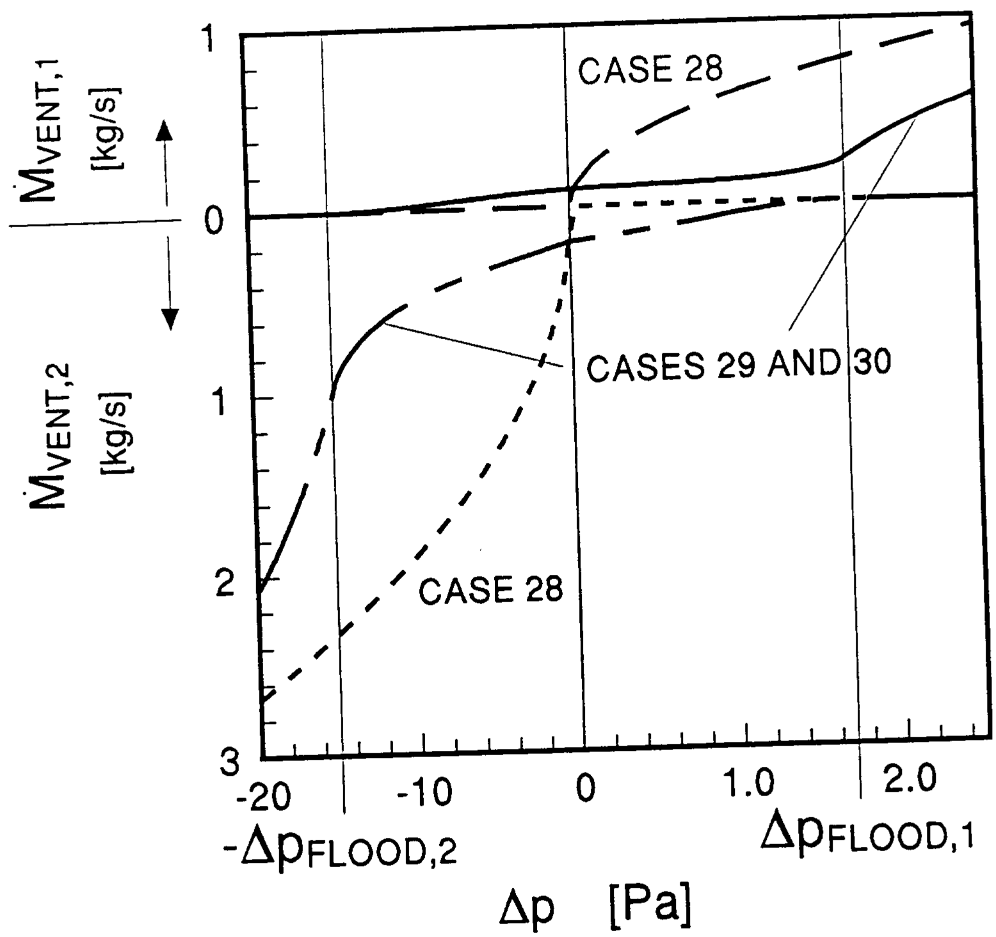

Figure 2. Plots of the calculated mass flow rate to upper space 1, $\dot{M}_{VENT,1}$, and to lower space 2, $\dot{M}_{VENT,2}$, as functions of the computed (fine-scale) cross-vent pressure difference, Δp, for Cases 28, 29, and 30 (see Table 1).

APPENDIX A (pages VENTCF2-1 to VENTCF2-22)

VENTCF2 - CALCULATION OF THE FLOW THROUGH A HORIZONTAL CEILING/FLOOR VENT CONNECTING TWO SPACES

APPENDIX B (pages VENTCF2A-1 to VENTCF2A-25)

VENTCF2A - CALCULATION OF THE FLOW THROUGH A HORIZONTAL CEILING/FLOOR VENT CONNECTING TWO SPACES WITH "SMOOTHING" OF LAYER EXTRACTION RATES AT TIMES OF RELATIVELY THIN ADJACENT-VENT LAYERS

VENTCF2 - CALCULATION OF THE FLOW THROUGH A HORIZONTAL CEILING/FLOOR VENT CONNECTING TWO SPACES

DESCRIPTION

Consider an instant of time during the simulation of a multi-room compartment fire environment. This algorithm calculates the flow of mass, enthalpy, oxygen, and other products of combustion through a horizontal vent located in a ceiling/floor partition common to any two inside rooms of the facility or between an inside room and the outside environment local to the vent. *VENTCF2*, is an advanced version of the algorithm/subroutine *VENTCF* [1] in that it includes an improved theoretical [2, 3] and experimental basis.

Depicted in Figure 1a is the vent and the two spaces when they are both inside rooms of a multi-room facility. Figures 1b and 1c depict the situation when the two spaces involve one inside room of the facility and one outside space, either above or below the room, in which is simulated the outside environment local to the vent.

As in Figure 1, designate the top space as space 1 and the bottom space as space 2. It is assumed that the temperature, density, concentration of oxygen and of other products of combustion of interest in the upper and lower layer of each inside room and in the environment local to the vent of an outside space are specified. Also specified in each inside room are: the elevation above the datum elevation of the floor, and the upper-layer/lower-layer interface; and the pressure at the floor above the specified datum pressure. Specified in an outside space are: a reference elevation above the datum elevation, and the pressure at this reference elevation above the specified datum pressure.

When the upper gas is less dense than the lower gas, i.e., the fluid configuration is stable, the flow through the vent is determined by a traditional orifice-type flow model. Then, flow is determined by the cross-vent pressure difference without any regard for buoyancy effects (see, e.g., [4] and [5]) and the present algorithm/subroutine is identical to that of *VENTCF* [1]. When the configuration is unstable and the upper gas is more dense than the lower gas, the effects of combined pressure and buoyancy forces can be significant. For example if the cross-vent pressure is relatively small, the unstable density configuration leads to an exchange-type of flow, with gas in the lower space rising into the upper space and gas from the upper space dropping into the lower space, where the flow rate from the high- to the low-pressure side of the vent is the larger of the two. Also, even when the cross-vent pressure difference large enough to produce uni-directional flow, the effect of buoyancy can be great enough to reduce significantly the flow rate from what it would be in the absence of a cross-vent density difference. In the present algorithm, for the case of unstable configurations the calculation of the flow between the two spaces is based on the theory and analysis of [3] and [2], respectively.

For unstable density configurations, the model of [2] and, therefore, the *VENTCF2* algorithm/subroutine itself is for flow through a circular, shallow (i.e., small ratio of depth to diameter), horizontal vent. It is also expected that the model will give reasonable estimates of flow even for non-circular vents, provided the aspect ratio (maximum-to-minimum span) of a vent shape of interest is not too much different than 1. Indeed, one of the example calculations of [2], which includes comparisons with some relevant experimental data, provides limited support for the applicability of the model in the case of square vents. However, **USE OF *VENTCF2* IN HIGH-ASPECT-RATIO AND/OR MODERATE-TO-LARGE-DEPTH VENT SCENARIOS IS NOT VALID** when cross-vent pressure differences are small-to-moderate compared to Δp_{FLOOD}. Results beyond those developed in [2] are required before the present work can be used for the latter types of vent shape.

The geometry and the conditions local to the vent which determine the characteristics of the vent flow are depicted in Figure 2. These include: the densities, ρ_1 and ρ_2, and the hydrostatic pressures, p_1 and p_2, at the elevation, but away from the immediate vicinity of the vent in the upper and lower spaces, respectively, and the area, A_V, and shape of the vent. Regarding the shape, at the present time results for horizontal vent flows are only available for circular or square vents. Other properties local to the vent and indicated in Figure 2 are T_1 and T_2, the absolute temperatures, $c_{O2,1}$ and $c_{O2,2}$, the concentrations of oxygen, and $c_{K,1}$ and $c_{K,2}$, K = 2 to N_{PROD}, the concentrations of a product of combustion K.

To simulate fire scenarios at times when vent flows are driven by arbitrarily high cross-vent pressure differences (i.e., when compressibility effects begin to be significant), whether for stable or unstable cross-vent density configurations, *VENTCF2* implements the ideas introduced in reference [5] and implemented previously in the algorithm/subroutines *VENTHP* [6] and *VENTCF* [1]. Such high cross-vent pressure differences could occur, for example, in fire scenarios involving flows through cracks in otherwise hermetically-sealed fire compartments.

The *VENTCF2* subroutine has been subjected to extensive parametric testing in a "stand-alone" mode [7].

OUTPUT

$c_{O2,1}$ [$c_{O2,2}$]

Concentration of oxygen in the top [bottom] space at the elevation of the vent. [(kg of oxygen)/(kg of layer)]

$c_{K,1}$ [$c_{K,2}$]

Concentration of product K in the top [bottom] space at the elevation of the vent. [(unit of product K)/(kg of layer)]

$c_{VENT,O2,I}$; I = 1 or 2

Concentration of oxygen in the component of the vent flow entering space I, provided such vent flow component is non-zero, i.e., provided $\dot{M}_{VENT,I}$, is non-zero. [(kg of oxygen)/(kg of vent flow)]

$c_{VENT,K,I}$; I = 1 or 2; K = 2 to NPROD

Concentration of product of combustion K in the component of the vent flow entering space I, provided such vent flow component is nonzero, i.e., provided $\dot{M}_{VENT,I}$ is non-zero. [(unit of product)/(kg of vent flow)]

$\dot{M}_{U,I}$ [$\dot{M}_{L,I}$]; I = 1 or 2

If space I is an inside room: Rate at which mass is <u>added</u> to the upper [lower] layer of room I due to the vent flow component which enters the other space. Note that this will <u>always be negative</u>, since the layer which supplies the material flowing to the other space will always have mass <u>extracted</u> from it. [W]

If space I is an "outside room": $\dot{M}_{U,I}$ is the rate at which mass is <u>added</u> to space I due to the vent flow component which enters the other space (i.e., the inside room). Note that this will <u>always be negative</u>, since an outside space which supplies material flowing through the vent to an adjacent space will always have mass <u>extracted</u> from it. $\dot{M}_{L,I}$ is identical to $\dot{M}_{U,I}$. [W]

$\dot{M}_{VENT,I}$; I = 1 to 2

Mass flow rate of the vent flow component entering space I. [kg/s]

$\dot{P}_{O2,L,I}$ [$\dot{P}_{O2,U,I}$] ; I = 1 or 2

If space I is an inside room: Rate at which oxygen is <u>added</u> to the upper [lower] layer of room I due to the vent flow component which enters the other space. Note that this will <u>always be negative</u>, since the layer which supplies the material flowing through the vent to the other space will always have its convected oxygen <u>extracted</u> from it. [(kg of O_2)/s]

If space I is an "outside room": $\dot{P}_{O2,U,I}$ is the rate at which oxygen is <u>added</u> to space I due to the vent flow component which enters the other space (i.e., the inside room). Note that this will <u>always be negative</u>, since an outside space which supplies material flowing through the vent to an adjacent space will always have its convected oxygen <u>extracted</u> from it. $\dot{P}_{O2,L,I}$ is identical to $\dot{P}_{O2,U,I}$. [(kg of O_2)/s]

$\dot{P}_{O2,VENT,I}$; I = 1 to 2

Mass flow rate of oxygen of the vent flow component entering space I. [(kg of oxygen)/s]

$\dot{P}_{K,L,I}$ [$\dot{P}_{K,U,I}$]; K = 2 to N_{PROD}; I = 1 or 2

If space I is an inside room: Rate at which product of combustion K is <u>added</u> to the upper [lower] layer of room I due to the vent flow component which enters the other space. Note that this will <u>always be negative</u> since the layer which supplies the material flowing through the vent to the other space will always have its convected product of combustion K <u>extracted</u> from it. [(unit of product K)/s]

If space I is an "outside room": $\dot{P}_{K,U,I}$ is the rate at which product of combustion K is <u>added</u> to space I due to the vent flow component which enters the other space (i.e., the inside room). Note that this will <u>always be negative</u>, since an outside space which supplies material flowing through the vent to an adjacent space will always have the convected product of combustion K <u>extracted</u> from it. $\dot{P}_{K,L,I}$ is identical to $\dot{P}_{K,U,I}$. [(unit of product K)/s]

$\dot{P}_{K,VENT,I}$; I = 1 to 2; K = 2 to N_{PROD}

Flow rate of product of combustion K in the vent flow component entering space I. [(unit of product K)/s]

p_1 [p_2]

Absolute hydrostatic pressure in the top [bottom] space at the elevation of the vent. [Pa = kg/(m·s²)]

$\dot{Q}_{U,I}$ [$\dot{Q}_{L,I}$]; I = 1 or 2

If space I is an inside room: Rate at which enthalpy <u>added</u> to the upper [lower] layer of room I due to the vent flow component which enters the other space. Note that this will <u>always be negative</u>, since the layer which supplies the material which flows to the other space will always have its convected enthalpy <u>extracted</u> from it. The enthalpy is based on the absolute temperature of the flow, $T_{VENT,I}$. [W]

If space I is an "outside room": $\dot{Q}_{U,I}$ is the rate at which enthalpy is added to space I due to the vent flow component which enters the other space (i.e., the inside room). Note that this will always be negative, since an outside space which supplies material which flows through the vent to an adjacent space will always have its convected enthalpy extracted from it. The enthalpy is based on the absolute temperature of the flow, $T_{U,I}$. $\dot{Q}_{L,I}$ is identical to $\dot{Q}_{U,I}$. [W]

$\dot{Q}_{VENT,I}$; I = 1 to 2

Total enthalpy flow rate in the vent flow component entering space I. This is based on the absolute temperature of the flow, $T_{VENT,I}$. [W]

T_1 [T_2]

Absolute temperature in the top [bottom] space at the elevation of the vent. [K]

$T_{VENT,I}$; I = 1 to 2

Absolute temperature of the vent flow component entering space I, provided such vent flow component is non-zero. [K]

Δp

$p_2 - p_1$, i.e., difference between the pressure in the bottom space at the elevation of the vent, and the pressure in the top space at the elevation of the vent. [Pa = kg/(m·s^2)]

ρ_1 [ρ_2]

Density in the top [bottom] space at the elevation of the vent. [kg/m$_3$]

$\rho_{VENT,I}$; I = 1 to 2

Density of the vent flow component entering space I, provided such vent flow component is nonzero. [kg/m^3]

INPUT

A_V

Area of the vent [m^2].

$c_{L,K,I}$ [$c_{U,K,I}$]; K = 2 to N_{PROD}; I = 1 or 2

If space I is an inside room: Concentration of product of combustion K in lower [upper] layer of room I if the volume of the lower [upper] layer is non-zero (if the lower [upper] layer volume is zero then the $c_{L,K,I}$ [$c_{U,K,I}$] value is not used in the calculation). [(unit of product K)/(kg of layer)]

If space I is an "outside room": $c_{L,K,I}$ is the uniform concentration throughout the space of product of combustion K; $c_{U,K,I}$ is specified as being identical to $c_{L,K,I}$. [(unit of product K)/(kg of local atmosphere)]

$c_{L,O2,I}$ [$c_{U,O2,I}$]; I = 1 or 2

If space I is an inside room: Concentration of oxygen in lower [upper] layer of room I if the volume of the lower [upper] layer is non-zero (if the lower [upper] layer volume is zero then the $c_{L,O2,I}$ [$c_{U,O2,I}$] value is not used in the calculation). [(kg of oxygen)/(kg of layer)]

If space I is an "outside room": $c_{L,O2,I}$ is the uniform concentration throughout the space of oxygen; $c_{U,O2,I}$ is specified as being identical to $c_{L,O2,I}$. [(kg of oxygen)/(kg of local atmosphere)]

C_p

Specific heat at constant pressure of the vent flow. [$W \cdot s/(kg \cdot K)$] (suggest 10^3 $W \cdot s/(kg \cdot K)$ for air as default)

N_{PMAX}

Maximum allowed number of products of combustion.

N_{PROD}

Number of products of combustion, including oxygen, being tracked in the simulation.

p_{DAT}

Datum absolute pressure. [$Pa = kg/(m \cdot s^2)$]

$T_{L,I}$ [$T_{U,I}$]; I = 1 or 2

If space I is an inside room: Absolute temperature of the lower [upper] layer in room I if the volume of the lower [upper] layer is non-zero (if the lower [upper] layer volume is zero then the $T_{L,I}$ [$T_{U,I}$] value is not used in the calculation). [K]

If space I is an "outside room": $T_{L,I}$ is the uniform absolute temperature there, taken to be the temperature at the reference elevation, $y_{REF,I}$; $T_{U,I}$ is specified as being identical to $T_{L,I}$. [K]

$y_{CEIL,I}$ [$y_{REF,I}$]

If space I is an inside room: Elevation of the ceiling [floor] of room I above the datum elevation. [m]

If space I is an "outside room": $y_{CEIL,I}$ and $y_{REF,I}$ are both identical and equal to the reference elevation of space I above the datum elevation, i.e., the specification must satisfy $y_{CEIL,I} \equiv y_{REF,I}$. The latter identity, which will never be satisfied for an inside room, is a characteristic of the input data used to distinguish an inside room from an "outside room." [m]

$y_{LAYER,I}$; I = 1 or 2

If space I is an inside room: Elevation of the upper/lower layer interface in room I above the datum elevation. [m]

If space I is an "outside room": $y_{LAYER,I}$ is specified as being identical to $y_{REF,I}$. [m]

y_{VENT}

Elevation of the vent above the datum elevation. Note that y_{VENT} must be identical to either $y_{CEIL,I}$ or $y_{REF,I}$ for each of the one or two inside rooms involved in the calculation. [m]

$\delta p_{REF,I}$; I = 1 or 2

Pressure at the reference elevation, $y_{REF,I}$, in space I above the datum absolute pressure, p_{DAT}. If space I is an inside room, then $\delta p_{REF,I}$ and $y_{REF,I}$ must correspond to the pressure and elevation, respectively, within the room and at the floor. [$Pa = kg/(m \cdot s^2)$]

ε_p

Error tolerance for $\delta p_{REF,I}$. If $p_{ERROR,I}$ is defined as the uncertainty in $\delta p_{REF,I}$, I = 1 or 2, then $p_{ERROR,I}$ satisfies

$$|p_{ERROR,I}| < \varepsilon_p p_0 + |\delta p_{REF,I}| \varepsilon_p$$

where $p_0 = 1.0Pa$. The first term is based on an absolute error tolerance and dominates the above error bound when $|\delta p_{REF,I}|$ is less than 1.0Pa. The second term is a relative error tolerance and dominates when $|\delta p_{REF,I}|$ is greater than 1.0Pa. ε_p should be chosen to be consistent with the tolerance specified for the computation of $\delta p_{REF,I}$ terms in the overall compartment fire model computer code which uses this algorithm.

$\rho_{L,I}$ [$\rho_{U,I}$]; I = 1 or 2

If space I is an inside room: Density of the lower [upper] layer in room I if the volume of the lower [upper] layer is non-zero (if the lower [upper] layer volume is zero then the $\rho_{L,I}$ [$\rho_{U,I}$] value is not used in the calculation). [kg/m^3]

If space I is an "outside room": $\rho_{L,I}$ is the uniform density there; $\rho_{U,I}$ is specified as being identical to $\rho_{L,I}$. [kg/m^3]

CALCULATION

1. Calculate p_I for I = 1 and 2 , and then Δp (the p_I calculation follows the *DELP* algorithm/subroutine of reference [8]):

$$p_I = \delta p_{REF,I} + \delta p_I + p_{DAT} \tag{1}$$

$$\Delta p = p_2 - p_1 = (\delta p_{REF,2} - \delta p_{REF,1}) + (\delta p_2 - \delta p_1) \tag{2}$$

where

$$\text{if } y_{REF,I} \le y_{VENT} \le y_{LAYER,I} \text{ then: } \delta p_I = -\rho_{L,I} g (y_{VENT} - y_{REF,I})$$
$$\text{else: } \delta p_I = -\rho_{L,I} g (y_{LAYER,I} - y_{REF,I}) - \rho_{U,I} g (y_{VENT} - y_{LAYER,I}) \tag{3}$$

and where g, the acceleration of gravity, is 9.8 m/s^2.

2. Calculate ρ_I, T_I, $c_{O2,I}$, and the $c_{K,I}$, K = 2 to N_{PROD}, for I = 1 and 2, and then $\Delta\rho$:

if $\{[(y_{VENT} = y_{REF,I}) \text{ and } (y_{LAYER,I} = y_{REF,I})] \text{ or } [(y_{VENT} = y_{CEIL,I}) \text{ and } (y_{LAYER,I} < y_{CEIL,I})]\}$ then:

$$\rho_I = \rho_{U,I},\ T_I = T_{U,I},\ c_{O2,I} = c_{U,O2,I},\ \text{and } c_{K,I} = c_{U,K,I} \tag{4}$$

else: $\rho_I = \rho_{L,I}$, $T_I = T_{L,I}$, $c_{O2,I} = c_{L,O2,I}$, and $c_{K,I} = c_{L,K,I}$

$$\Delta\rho = \rho_1 - \rho_2 \tag{5}$$

3. Define $\dot{V}_{ST,HIGH}$ as the volume rate of flow through the vent, from the high- to the low-pressure space, that is predicted with a "standard," uni-directional-flow-type calculation (i.e., without regard to the effect of buoyancy, in general, or the stability of the cross-vent density configuration, in particular), where arbitrarily high cross-vent pressures are allowed. Here, the calculation follows the model of [5] as implemented in the *VENTHP* algorithm/subroutine of [6]. Calculate $\dot{V}_{ST,HIGH}$:

If $\Delta p = 0$ then: $\dot{V}_{ST,HIGH} = 0$; skip to (the next) item 4 of the **CALCULATION** (6)

If $\Delta p > 0$ or $\Delta p < 0$ then:

a. Define and compute ρ_{HIGH}, ε, and x:

If $\Delta p > 0$, i.e., "standard" flow from (lower) space 2 to (upper) space 1, then:

$$\rho_{HIGH} = \rho_2;\ \ \varepsilon = \Delta p/p_2 \tag{7}$$

If $\Delta p < 0$, i.e., "standard" flow from (upper) space 1 to (lower) space 2, then:

$$\rho_{HIGH} = \rho_1;\ \ \varepsilon = -\Delta p/p_1 \tag{8}$$

$$x = 1 - \varepsilon \tag{9}$$

b. Compute C(x), the vent flow coefficient, and w(x):

$$C(x) = 0.85 - 0.25x = 0.60 + 0.25\varepsilon \tag{10}$$

$$w(x) = \begin{cases} 1 - [3/(4\gamma)]\varepsilon & \text{if } 0 < \varepsilon \le 10^{-5} \\ f(x)/[2\varepsilon]^{1/2} & \text{if } 1 \ge \varepsilon > 10^{-5} \end{cases} \tag{11}$$

where

$$f(x) = \begin{cases} \{[2\gamma/(\gamma - 1)]x^{2/\gamma}[1 - x^{(\gamma - 1)/\gamma}]\}^{1/2} & \text{if } \varepsilon < 1 - [2/(\gamma + 1)]^{\gamma/(\gamma - 1)} \\ \{\gamma[2/(\gamma + 1)]^{(\gamma + 1)/(\gamma - 1)}\}^{1/2} & \text{if } \varepsilon \ge 1 - [2/(\gamma + 1)]^{\gamma/(\gamma - 1)} \end{cases} \tag{12}$$

and where γ, the ratio of specific heats of the vent flow gas, is taken to be that of air, 1.40. Note that for the present horizontal vent application, the C(x) of Eq. (10) is taken to be consistent with the standard incompressible limit for flow through circular sharp-edged orifices in the sense that $C \rightarrow 0.60$ as $\varepsilon \rightarrow 0$ [9].

c. Define and compute $\Delta p_{CUT}^{1/2}$:

$$\Delta p_{CUT}^{1/2} \equiv [\varepsilon_p \mathrm{MAX}(1.0\mathrm{Pa},\ |\delta p_{REF,1}|,\ |\delta p_{REF,2}|)]^{1/2} \quad (13)$$

d. Define and compute F_{NOISE}, a numerical damping factor, and then $\dot{V}_{ST,HIGH}$:

$$F_{NOISE} = 1.0 - \exp(-|\Delta p|^{1/2}/\Delta p_{CUT}^{1/2}) \quad (14)$$

$$\dot{V}_{ST,HIGH} = F_{NOISE} C(x) w(x) (2/\rho_{HIGH})^{1/2} A_V |\Delta p|^{1/2} \quad (15)$$

The term F_{NOISE} of Eq. (14) is designed to damp out the numerical noise (error) in the calculated value for Δp that would otherwise be dominant in Eq. (15) when Δp is small relative to the maximum of 1.0 pascal and the calculated reference pressures, $\delta p_{REF,1}$, $\delta p_{REF,2}$. The term Δp_{CUT} of Eq. (13) is an estimate of how small the maximum of $|\Delta p|$ must be to retain a few digits of accuracy in the calculation of Δp. When the calculated value of $|\Delta p|$ is smaller than p_{CUT}, this value and, therefore, the value of $\dot{V}_{ST,HIGH}$ in Eq. (15) will likely contain noise which should be damped. F_{NOISE} is constructed to tend towards 1 when $|\Delta p|$ is large relative to Δp_{CUT} and tends towards 0 when $|\Delta p|$ is small relative to Δp_{CUT}.

4. When the cross-vent density configuration is unstable ($\Delta\rho > 0$), mixed pressure- and buoyancy-driven aspects of the flow have to be considered and the vent flow rates are calculated according to [2]. Define $\dot{V}_{B,HIGH}$, $\dot{V}_{B,LOW}$ as the reference-[2], buoyancy-affected, volume flow rates across the vent from the high-to-low and low-to-high pressure spaces, respectively.

If $\Delta\rho \leq 0$: $\dot{V}_{B,HIGH} = \dot{V}_{B,LOW} = 0$; skip to (the next) item 5 of the **CALCULATION** (17)

a. Calculate $\bar{T}$, $\bar{\rho}$, $\mu(\bar{T})$ in m²/s from [10], and $\varepsilon > 0$:

$$\bar{T} = (T_1 + T_2)/2;\ \ \bar{\rho} = (\rho_1 + \rho_2)/2;$$
$$\mu(\bar{T}) = \bar{\rho}[0.04128(10^{-7})\bar{T}^{5/2}/(\bar{T} + 110.4)];\ \ \varepsilon = \Delta\rho/\bar{\rho} > 0 \quad (18)$$

b. Calculate D and $\bar{G}r$; if $p_2 > p_1$, i.e., $\Delta p > 0$, then replace ε by $-\varepsilon < 0$:

$$D = (4A_V/\pi)^{1/2};\ \ \bar{G}r = 2gD^3|\varepsilon|/[\mu(\bar{T})/\bar{\rho}]^2;\ \ \text{if } \Delta p > 0 \text{ then } \varepsilon = -\varepsilon \quad (19)$$

c. Calculate conditions at the limit of uni-directional flow (i.e., the flooding condition) and the relative pressure, δp^*:

$$\dot{V}_{HIGH,FLOOD} = 0.1754 A_V (2gD|\varepsilon|)^{1/2} \exp(0.5536\varepsilon);$$
$$\Delta p_{FLOOD} = 0.2427(4g\Delta\rho D)(1 + \varepsilon/2)\exp(1.1072\varepsilon); \quad (20)$$
$$\delta p^* = |\Delta p|/\Delta p_{FLOOD}$$

d. Calculate σ_1, σ_2 and then $V_{B,LOW}$, $V_{B,HIGH}$:

$$\sigma_1 = F_{NOISE} C(x) w(x)/0.1780;\ \ \sigma_2 = 1.045 \quad (21)$$

If $\delta p^* \geq 1$, expect uni-directional flow:

$$V_{B,LOW} = 0 \tag{22}$$

$$\dot{V}_{B,HIGH} = \dot{V}_{HIGH,FLOOD}\{1 - \sigma_2^2 + [\sigma_2^4 + \sigma_1^2(\delta p^* - 1)]^{1/2}\}$$

If $\delta p^* < 1$, expect mixed flow:

$$\dot{V}_{EX,MAX} = 0.055(4/\pi)A_V(gD|\varepsilon|)^{1/2} \tag{23}$$

$$m_3 = -0.7070; \quad M = (\sigma_1/\sigma_2)^2 - 1$$

$$\dot{V}_{B,LOW} = \dot{V}_{EX,MAX}[(1 + m_3/2)(1 - \delta p^*)^2 - (2 + m_3/2)(1 - \delta p^*)]^2 \tag{24}$$

$$\dot{V}_{B,HIGH} = \dot{V}_{B,LOW} + \{M - [1 + (M^2 - 1)(1 - \delta p^*)]^{1/2}\}\dot{V}_{HIGH,FLOOD}/(M - 1)$$

(Note: σ_1 of Eq. (21) is somewhat different than σ_1 in [2]. The modification here is provide for an analytic representation of vent flow which is continuous and uniformly valid even as δp^* is increased to a level where compressibility effects become important. The result of [2] does not include the effect of compressibility.)

5. Following [2], when $\Delta\rho > 0$ the above will be taken as the flow solution provided $\bar{G}r \geq 2(10^7)$. For smaller $\bar{G}r$, the reference-[2] solution begins to loose its validity, and there is no existing model for the flows the range $0 < \bar{G}r < 2(10^7)$. However, it is clear that the above-calculated "standard" flow must be approached as $\bar{G}r \rightarrow 0$.

Consistent with the above comments, when $\bar{G}r$ is in the range $0 \leq \bar{G}r < 2(10^7)$, the vent flow will be estimated by:

flow = ("standard" flow) + [(reference-[2] flow) - ("standard" flow)]$\bar{G}r/[2(10^7)]$

a. Define $\dot{V}_{HIGH}$ and $\dot{V}_{LOW}$ as the volume flow rates across the vent from the high-to-low and low-to-high pressure spaces, respectively.

If $\Delta\rho \leq 0$: $\dot{V}_{HIGH} = \dot{V}_{ST,HIGH}$; $\dot{V}_{LOW} = 0$ (25)

If $\Delta\rho > 0$ and $0 < \bar{G}r < 2(10^7)$:

$$\dot{V}_{HIGH} = \dot{V}_{ST,HIGH} + (\dot{V}_{B,HIGH} - \dot{V}_{ST,HIGH})\bar{G}r/[2(10^7)] \tag{26}$$

$$\dot{V}_{LOW} = \dot{V}_{B,LOW}\bar{G}r/[2(10^7)]$$

If $\Delta\rho > 0$ and $\bar{G}r \geq 2(10^7)$: $\dot{V}_{HIGH} = \dot{V}_{B,HIGH}$; $\dot{V}_{LOW} = \dot{V}_{B,LOW}$ (27)

b. Define and calculate $\dot{V}_{VENT,I}$, I = 1 and 2, as the vent volume flow rate entering space I.

If $\Delta p \geq 0$: $\dot{V}_{VENT,1} = \dot{V}_{HIGH}$; $\dot{V}_{VENT,2} = \dot{V}_{LOW}$ (28)

(i.e., flow to the upper space is the flow from the high- to the low-pressure space, and flow to the lower space is the flow from the low- to the high-pressure space)

If $\Delta p < 0$: $\dot{V}_{VENT,1} = \dot{V}_{LOW}$; $\dot{V}_{VENT,2} = \dot{V}_{HIGH}$ (29)

(i.e., flow to the upper space is the flow from the low- to the high-pressure space, and flow to the lower space is the flow from the high- to the low-pressure space)

6. Calculate the vent flow properties $\rho_{VENT,I}$, $T_{VENT,I}$, $c_{VENT,O2,I}$, $c_{VENT,K,I}$, $K = 2$ to N_{PROD}, $I = 1$ and 2:

$$\rho_{VENT,1} = \rho_2(p_1/p_2),\ \rho_{VENT,2} = \rho_1(p_2/p_1);\ T_{VENT,1} = T_2,\ T_{VENT,2} = T_1; \tag{30}$$

$$c_{VENT,O2,1} = c_{O2,2},\ c_{VENT,O2,2} = c_{O2,1};\ c_{VENT,K,1} = c_{K,2},\ c_{VENT,K,2} = c_{K,1},\ K = 2 \text{ to } N_{PROD}$$

7. Calculate the vent flow rates $\dot{M}_{VENT,I}$, $I = 1$ and 2:

$$\dot{M}_{VENT,I} = \rho_{VENT,I}\dot{V}_{VENT,I} \tag{31}$$

8. Calculate the vent flow rates $\dot{Q}_{VENT,I}$, $\dot{P}_{O2,VENT,I}$, $\dot{P}_{K,VENT,I}$, $K = 2$ to N_{PROD}, $I = 1$ and 2:

$$\dot{Q}_{VENT,I} = \dot{M}_{VENT,I}C_pT_{VENT,I};\ \dot{P}_{O2,VENT,I} = \dot{M}_{VENT,I}c_{VENT,O2,I}; \tag{32}$$

$$\dot{P}_{K,VENT,I} = \dot{M}_{VENT,I}c_{VENT,K,I},\ K = 2 \text{ to } N_{PROD}$$

9. Calculate rates at which flows are added to layers of each space as a result of the vent flow extracted from it. First consider space 1 ($I = 1$, $J = 2$) and then space 2 ($I = 2$, $J = 1$). For either case:

If $\{[(y_{VENT} = y_{REF,I})$ and $(y_{LAYER,I} = y_{REF,I})]$ or $[(y_{VENT} = y_{CEIL,I})$ and $(y_{LAYER,I} < y_{CEIL,I})]\}$ (i.e., the vent flow to room J is extracted from the upper layer of room I and, if space I is an inside room, the lower layer of room I is unchanged) then:

$$\dot{M}_{U,I} = -\dot{M}_{VENT,J},\ \dot{M}_{L,I} = 0;\ \dot{Q}_{U,I} = -\dot{Q}_{VENT,J},\ \dot{Q}_{L,I} = 0; \tag{33}$$

$$\dot{P}_{O2,U,I} = -\dot{P}_{O2,VENT,J},\ \dot{P}_{O2,L,I} = 0;\ \dot{P}_{K,U,I} = -\dot{P}_{K,VENT,J},\ \dot{P}_{K,L,I} = 0$$

If $y_{REF,I} = y_{CEIL,I}$ (i.e., space I is an outside space) modify the results of Eqs. (33) as follows:

$$\dot{M}_{L,I} = \dot{M}_{U,I};\ \dot{Q}_{L,I} = \dot{Q}_{U,I};\ \dot{P}_{O2,L,I} = \dot{P}_{O2,U,I};\ \dot{P}_{K,L,I} = \dot{P}_{K,U,I} \tag{34}$$

If the condition above Eqs. (33) is not satisfied (i.e., the vent flow to room J is extracted from the lower layer of room I and, if space I is an inside room, the upper layer of room I is unchanged) then:

$$\dot{M}_{L,I} = -\dot{M}_{VENT,J},\ \dot{M}_{U,I} = 0;\ \dot{Q}_{L,I} = -\dot{Q}_{VENT,J},\ \dot{Q}_{U,I} = 0; \tag{35}$$

$$\dot{P}_{O2,L,I} = -\dot{P}_{O2,VENT,J},\ \dot{P}_{O2,U,I} = 0;\ \dot{P}_{K,L,I} = -\dot{P}_{K,VENT,J},\ \dot{P}_{K,U,I} = 0$$

If $y_{REF,I} = y_{CEIL,I}$ (i.e., space I is an outside space) modify the results of Eqs. (35) as follows:

$$\dot{M}_{U,I} = \dot{M}_{L,I};\ \dot{Q}_{U,I} = \dot{Q}_{L,I};\ \dot{P}_{O2,U,I} = \dot{P}_{O2,L,I};\ \dot{P}_{K,U,I} = \dot{P}_{K,L,I} \tag{36}$$

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SUBROUTINE VARIABLES

All nomenclature in the subroutine is identical to the nomenclature used above except for:

A_V	-	AVENT [m^2]
C	-	COEF

c_p	-	CP [W·s/(kg·K)]
$c_{L,K,l}$, $c_{U,K,l}$	-	CONL(K,I), CONU(K,I), I = 1 or 2 [(unit of product K)/(kg of layer)]
$c_{L,O2,l}$, $c_{U,O2,l}$	-	CONL(1,I), CONU(1,I), I = 1 or 2 [(kg of oxygen)/(kg of layer)]
$c_{VENT,K,l}$	-	CVENT(K,I), I= 1 or 2 [(unit of product K)/(kg of vent flow)
$c_{VENT,O2,l}$	-	CVENT(1,I), I = 1 or 2 [(kg of oxygen)/(kg of vent flow)]
$c_{K,l}$	-	C(K,I), I= 1 or 2 [(unit of product K)/(kg of vent flow)
$c_{O2,l}$	-	C(1,I), I = 1 or 2 [(kg of oxygen)/(kg of vent flow)]
F_{NOISE}	-	FNOISE [dimensionless]
f	-	FF [dimensionless]
$\bar{G}r$	-	GR [dimensionless]
g	-	9.8 m/s^2
M	-	XM [dimensionless]
$\dot{M}_{L,l}$, $\dot{M}_{U,l}$	-	XML(I), XMU(I), I = 1 or 2 [kg/s]
$\dot{M}_{VENT,l}$	-	XMVENT(I), I = 1 or 2 [kg/s]
m_3	-	XM3 [dimensionless]
N_{PMAX}	-	NPMAX [dimensionless]
N_{PROD}	-	NPROD [dimensionless]
$\dot{P}_{K,L,l}$, $\dot{P}_{K,U,l}$	-	PL(K,I), PU(K,I), I = 1 or 2 [(unit of product K)/s]
$\dot{P}_{K,VENT,l}$	-	PVENT(K,I), I = 1 or 2 [(unit of product K)/s]
$\dot{P}_{O2,L,l}$, $\dot{P}_{O2,U,l}$	-	PL(1,I), PU(1,I), I = 1 or 2 [(kg of oxygen)/s]
$\dot{P}_{O2,VENT,l}$	-	PVENT(1,I), I = 1 or 2 [(kg of oxygen)/s]
p_{DAT}	-	PDATUM [Pa = $kg/(m \cdot s^2)$]
p_l	-	P(I), I = 1 or 2 [Pa = $kg/(m \cdot s^2)$]
$\dot{Q}_{L,l}$, $\dot{Q}_{U,l}$	-	QL(I), QU(I), I = 1 or 2 [W]
$\dot{Q}_{VENT,l}$	-	QVENT(I), I = 1 or 2 [W]

$\bar{T}$	-	TBAR [K]
T_I	-	T(I), I = 1 or 2 [K]
$T_{L,I}$, $T_{U,I}$	-	TL(I), TU(I), I = 1 or 2 [K]
$T_{VENT,I}$	-	TVENT(I), I = 1 or 2 [K]
$\dot{V}_{B,HIGH}$	-	VBHIGH = VB(1) if $\Delta p \geq 0$, = VB(2) if $\Delta p \leq 0$ [m^3/s]
$\dot{V}_{B,LOW}$	-	VBLOW = VB(2) if $\Delta p \geq 0$, = VB(1) if $\Delta p \leq 0$ [m^3/s]
$\dot{V}_{EX,MAX}$	-	VEXMAX [m^3/s]
$\dot{V}_{HIGH}$, $\dot{V}_{LOW}$	-	VHIGH, VLOW [m^3/s]
$\dot{V}_{HIGH,FLOOD}$	-	VHIGHFL [m^3/s]
$\dot{V}_{ST,HIGH}$	-	V = VST(1) if $\Delta p > 0$, = VST(2) if $\Delta p < 0$ [m^3/s]
$\dot{V}_{VENT,I}$	-	VVENT(I), I = 1 or 2 [m^3/s]
w	-	W [dimensionless]
x	-	X [dimensionless]
$y_{CEIL,I}$	-	YCEIL(I), I = 1 or 2 [m]
$y_{LAYER,I}$	-	YLAY(I), I = 1 or 2 [m]
$y_{REF,I}$	-	YREF(I), I = 1 or 2 [m]
y_{VENT}	-	YVENT [m]
γ	-	1.40
Δp	-	DELP [Pa = $kg/(m \cdot s^2)$]
$\Delta p_{CUT}^{1/2}$	-	DPC1D2 [Pa = $kg/(m \cdot s^2)$]
Δp_{FLOOD}	-	DELPFD [Pa = $kg/(m \cdot s^2)$]
$\Delta \rho$	-	DELDEN [kg/m^3]
δp_*	-	DPDDPFL [Pa = $kg/(m \cdot s^2)$]
δp_I	-	DP(I), I = 1 or 2 [Pa = $kg/(m \cdot s^2)$]
$\delta p_{REF,I}$	-	DPREF(I), I = 1 or 2 [Pa = $kg/(m \cdot s^2)$]
ε	-	EPS [dimensionless]

ε_p	-	EPSP [dimensionless]
μ	-	XMEW [m^2/s]
ρ_{HIGH}	-	DENHIGH [kg/m^3]
$\bar{\rho}$	-	DENBAR [kg/m^3]
ρ_I	-	DEN(I), I = 1 or 2 [kg/m^3]
$\rho_{L,I}$, $\rho_{U,I}$	-	DENL(I), DENU(I), I = 1 or 2 [kg/m^3]
$\rho_{VENT,I}$	-	DENVNT(I), I = 1 or 2 [kg/m^3]
σ_1	-	SIGMA1 [dimensionless]
σ_2	-	SIGMA2 [dimensionless]

PREPARED BY

Leonard Y. Cooper
December 1993

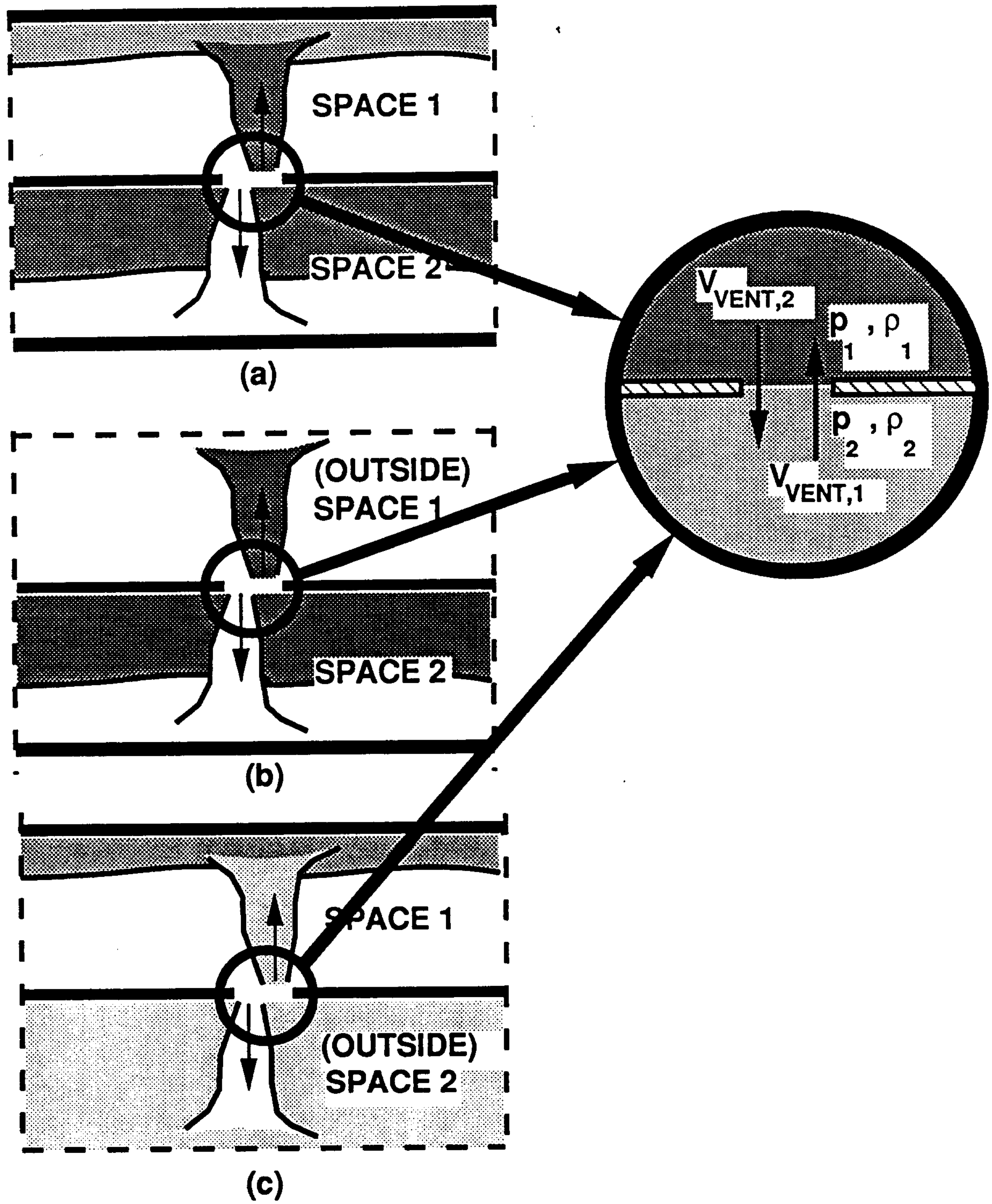

Figure 1. The possible configurations of the two spaces joined by a horizontal ceiling/floor vent with space 1 above space 2: a) two inside rooms; b) an outside space above an inside room; c) an inside room over an outside space.

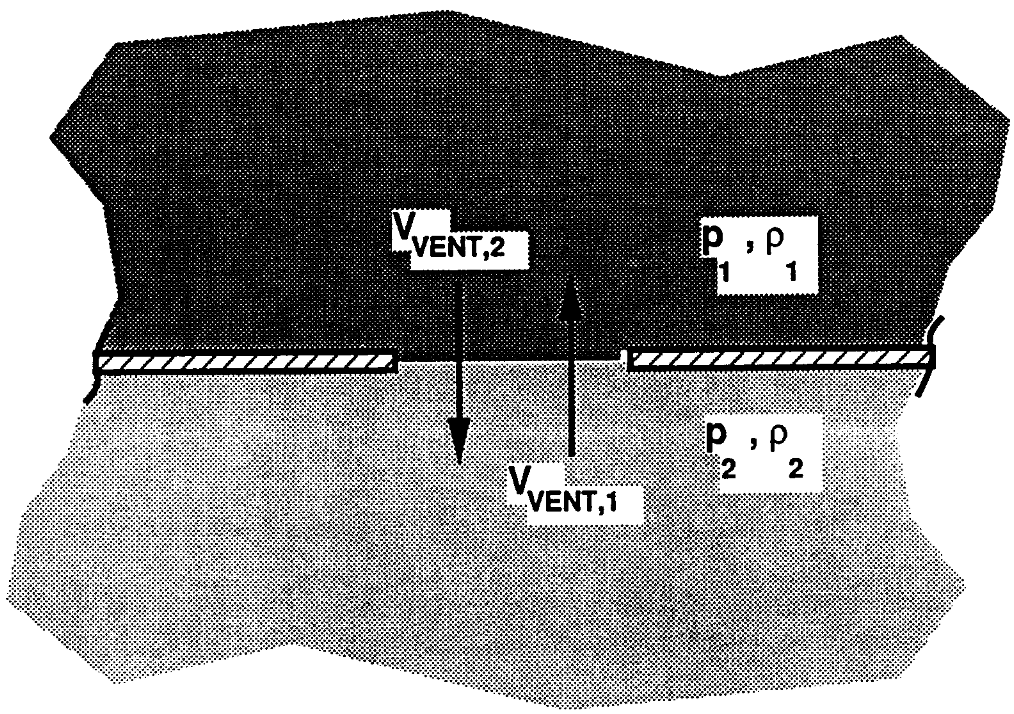

Figure 2. The geometry and conditions local to a horizontal ceiling/floor vent which determine the characteristics of the vent flow.

SUBROUTINE VENTCF2

```
      SUBROUTINE VENTCF2(
     I     AVENT,CONL,CONU,CP,NPMAX,NPROD,PDATUM,TL,TU,
     I     YCEIL,YREF,YLAY,YVENT,DPREF,EPSP,DENL,DENU,
     O     C,CVENT,XML,XMU,XMVENT,PL,PU,PVENT,P,QL,QU,QVENT,T,TVENT,
     O     DELP,DEN,DENVNT)
      INCLUDE PRECIS.INC
C*BEG
C*** VENTCF -  CALCULATION OF THE FLOW OF MASS, ENTHALPY, OXYGEN AND
C             OTHER PRODUCTS OF COMBUSTION THROUGH A HORIZONTAL
C             VENT JOINING AN UPPER SPACE 1 TO A LOWER SPACE 2. THE
C             SUBROUTINE USES INPUT DATA DESCRIBING THE TWO-LAYER
C             ENVIRONMENT OF INSIDE ROOMS AND THE UNIFORM
C             ENVIRONMENT IN OUTSIDE SPACES.
C
C*** SUBROUTINE ARGUMENTS
C
C  INPUT
C  -----
C  AVENT          -     AREA OF THE VENT [M**2]
C  CONL(K,I)      -     CONCENTRATION OF PRODUCT K IN LOWER LAYER OF AN INSIDE
C                       ROOM I OR UNIFORM CONCENTRATION OF PRODUCT K IN AN
C                       OUTSIDE SPACE I [(UNIT OF PRODUCT)/(KG LAYER)]
C  CONL(K,I)      -     CONCENTRATION OF PRODUCT K IN UPPER LAYER OF AN INSIDE
C                       ROOM I OR UNIFORM CONCENTRATION OF PRODUCT K IN AN
C                       OUTSIDE SPACE I [(UNIT OF PRODUCT)/(KG LAYER)]
C  CP             -     SPECIFIC HEAT [W*S/(KG*K)]
C  NPMAX          -     MAXIMUM ALLOWED NUMBER OF PRODUCTS
C  NPROD          -     NUMBER OF PRODUCTS IN CURRENT SCENARIO
C  PDATUM         -     DATUM ABSOLUTE PRESSURE [PA = KG/(M*S**2)]
C  TL(I)          -     TEMPERATURE OF LOWER LAYER OF AN INSIDE ROOM I OR
C                       TEMPERATURE OF AN OUTSIDE SPACE I [K]
C  TU(I)          -     TEMPERATURE OF UPPER LAYER OF AN INSIDE ROOM I OR
C                       TEMPERATURE OF AN OUTSIDE SPACE I [K]
C  YCEIL(I)       -     HEIGHT OF CEILING ABOVE DATUM ELEVATION FOR AN INSIDE
C                       ROOM I OR YREF(I) FOR AN OUTSIDE SPACE I [M]
C  YREF(I)        -     HEIGHT OF REFERENCE ELEVATION FOR SPACE I ABOVE DATUM
C                       ELEVATION [M]
C  YLAY(I)        -     HEIGHT OF LAYER ABOVE DATUM ELEVATION FOR AN INSIDE
C                       ROOM I OR YREF(I) FOR AN OUTSIDE SPACE I [M]
C  YVENT          -     HEIGHT OF VENT ABOVE DATUM ELEVATION [M]
C  DPREF(I)       -     PRESSURE IN SPACE I AT ITS REFERENCE ELEVATION ABOVE
C                       DATUM ABSOLUTE PRESSURE [PA = KG/(M*S**2)]
C  EPSP           -     ERROR TOLERANCE FOR DPREF [DIMENSIONLESS]
C  DENL(I)        -     DENSITY OF LOWER LAYER OF AN INSIDE ROOM I OR DENSITY
C                       OF AN OUTSIDE SPACE I [KG/M**3]
C  DENU(I)        -     DENSITY OF UPPER LAYER OF AN INSIDE ROOM I OR DENSITY
C                       OF AN OUTSIDE SPACE I [KG/M**3]
C
C
C  OUTPUT
C  ------
C  C(K,I)         -     CONCENTRATION OF EACH PRODUCT IMMEDIATELY ABOVE (IN
C                       SPACE I = 1) AND BELOW (IN SPACE I = 2) THE VENT
C                       [(UNIT OF PRODUCT)/(KG LAYER)]
C  CVENT(I)       -     CONCENTRATION OF EACH PRODUCT IN THE VENT FLOW
C                       COMPONENT ENTERING SPACE I [(UNIT OF PRODUCT)/(KG OF
C                       VENT FLOW)]
C  XML(I)         -     RATE AT WHICH MASS IS ADDED TO THE LOWER LAYER OF AN
C                       INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I =
C                       1 (I = 2) DUE TO THE VENT FLOW COMPONENT ENTERING
C                       SPACE = 2 (I = 1) [KG/S]
C  XMU(I)         -     RATE AT WHICH MASS IS ADDED TO THE UPPER LAYER OF AN
C                       INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I = 1
C                       (I = 2) DUE TO THE VENT FLOW COMPONENT ENTERING SPACE
C                       I = 2 (I = 1) [KG/S]
C  XMVENT(I)      -     MASS FLOW RATE IN THE VENT FLOW COMPONENT ENTERING
C                       SPACE I [KG/S]
C  PL(K,I)        -     RATE AT WHICH PRODUCT K IS ADDED TO THE LOWER LAYER OF
```

```
C                              AN INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I
C                              = 1 (I = 2) DUE TO THE VENT FLOW CONPONENT ENTERING
C                              SPACE I = 2 (I = 1) [(UNIT OF PRODUCT)/S]
C  PU(K,I)          -          RATE AT WHICH PRODUCT K IS ADDED TO THE UPPER LAYER OF
C                              AN INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I
C                              = 1 (I = 2) DUE TO THE VENT FLOW COMPONENT ENTERING
C                              SPACE I = 2 (I = 1) [(UNIT OF PRODUCT)/S]
C  PVENT(K,I)       -          FLOW RATE OF PRODUCT K IN THE VENT FLOW COMPONENT
C                              ENTERING SPACE I [(UNIT OF PRODUCT)/S]
C  P(I)             -          ABSOLUTE PRESSURE IMMEDIATELY ABOVE (IN SPACE I = 1)
C                              AND BELOW (IN SPACE I = 2) THE VENT [PA = KG/(M*S**2)]
C  QL(I)            -          RATE AT WHICH ENTHALPY IS ADDED TO THE LOWER
C                              LAYER OF AN INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE
C                              SPACE I = 1 (I = 2) DUE TO THE VENT FLOW COMPONENT
C                              ENTERING SPACE I = 2 (I = 1) [W]
C  QU(I)            -          RATE AT WHICH ENTHALPY IS ADDED TO THE UPPER LAYER OF
C                              AN INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I
C                              = 1 (I = 2) DUE TO THE VENT FLOW COMPONENT ENTERING
C                              SPACE I = 2 (I = 1) [W]
C  QVENT(I)         -          FLOW RATE OF ENTHALPY IN THE VENT FLOW COMPONENT
C                              ENTERING SPACE I [W]
C  T(I)             -          ABSOLUTE TEMPERATURE IMMEDIATELY ABOVE (IN SPACE I =
C                              1) AND BELOW (IN SPACE I = 2) THE VENT [K]
C  TVENT(I)         -          ABSOLUTE TEMPERATURE OF THE VENT FLOW COMPONENT
C                              ENTERING SPACE I [K]
C  DELP             -          CROSS-VENT PRESSURE DIFFERENCE, P(2) - P(1), [PA =
C                              KG/(M*S**2)]
C  DEN(I)           -          DENSITY IMMEDIATELY ABOVE (IN SPACE I = 1) AND BELOW
C                              (IN SPACE I = 2) THE VENT [KG/M**3]
C  DENVNT(I)        -          DENSITY OF THE VENT FLOW COMPONENT ENTERING SPACE I
C                              [KG/M**3]
C
C*END
C****
C**** NOTE THAT NPMAX2 SHOULD BE BIGGER THAT NPMAX
C****
      PARAMETER (NPMAX2=10)
            DIMENSION CONL(NPMAX2,2), CONU(NPMAX2,2), TL(2), TU(2)
            DIMENSION YCEIL(2), YREF(2), YLAY(2), DPREF(2)
            DIMENSION DENL(2), DENU(2)
            DIMENSION C(NPMAX2,2), CVENT(NPMAX2,2), XML(2), XMU(2)
            DIMENSION XMVENT(2)
            DIMENSION PL(NPMAX2,2), PU(NPMAX2,2), PVENT(NPMAX2,2), P(2)
            DIMENSION QL(2),QU(2)
            DIMENSION QVENT(2), T(2), TVENT(2), DEN(2), DENVNT(2)
            DIMENSION DP(2),VB(2),VST(2), VVENT(2)
            PARAMETER (GAM=1.40D0)
            DATA IFIRST/0/
            SAVE IFIRST,GAMCUT,GAMMAX
            PARAMETER (G=9.80D0)
            PARAMETER (PI=3.141592654D0)
            PARAMETER (SIGMA2=1.045D0)
            PARAMETER (XM3=-0.7070D0)
            GR=0.D0
            VHIGHFL=0.D0
            DELPFL=0.D0
            DO 5 I=1,2
            VST(I)=0.D0
            VB(I)=0.D0
            QVENT(I)=0.D0
            XMVENT(I)=0.D0
            DO 2 NP=1,NPROD
            PVENT(NP,I)=0.D0
    2       CONTINUE
    5       CONTINUE
C
C***        THE FOLLOWING CODE SEGMENT COMPUTES CONSTANTS REQUIRED BY VENTCF2.
C***        IT IS EXECUTED THE FIRST TIME VENTCF IS CALLED.
C
```

```
      IF(IFIRST.EQ.0)THEN
               IFIRST = 1
               GAMCUT = (2.0D0/(GAM+1.0D0))**(GAM/(GAM-1.0D0))
               ZZZ=GAM*((2.0D0/(GAM+1.0D0))**((GAM+1.0D0)/(GAM-1.0D0)))
               GAMMAX = DSQRT(ZZZ)
      ENDIF
C
C*** 1. AND 2.  CALCULATE THE P(I), DELP, THE OTHER PROPERTIES
C***            ADJACENT TO THE TWO SIDES OF THE VENT, AND DELDEN.
C
      DO 10 I = 1, 2
               IF(YREF(I).LE.YVENT.AND.YVENT.LE.YLAY(I))THEN
C
C***   THE VENT IS AT OR BELOW THE REFERENCE ELEVATION IN SPACE I. IF
C***   SPACE I IS AN INSIDE ROOM THEN BOTH THE VENT AND THE LAYER
C***   INTERFACE ARE AT THE FLOOR ELEVATION.
C
                        DP(I) = - G*DENL(I)*(YVENT - YREF(I))
               ELSE
C
C***   THE VENT IS ABOVE THE REFERENCE ELEVATION IN SPACE I.
C***   IF SPACE I IS AN INSIDE ROOM THEN THE VENT IS AT THE
C***   CEILING.
C
                        DP(I) = - G*DENL(I)*(YLAY(I)-YREF(I))
     $                       - G*DENU(I)*(YVENT-YLAY(I))
               ENDIF
               P(I) = DPREF(I) + DP(I) + PDATUM
10    CONTINUE
C
C***   DELP IS PRESSURE IMMEDIATELY BELOW THE VENT LESS PRESSURE
C***   IMMEDIATELY ABOVE THE VENT.
C
      DELP = (DPREF(2)-DPREF(1))+(DP(2)-DP(1))
      DO 30 I = 1, 2
               DEN(I) = 0.0D0
               T(I) = 0.0D0
               DO 22 K = 1, NPROD
                        C(K,I) = 0.0D0
22             CONTINUE
               IF(((YVENT.EQ.YREF(I)).AND.((YLAY(I)-YREF(I)).LT.0.D0))
     $   .OR.((YVENT.EQ.YCEIL(I)).AND.((YCEIL(I)-YLAY(I))
     $                           .GT.0.D0)))THEN
               DEN(I) = DENU(I)
                        T(I) = TU(I)
                        DO 24 K = 1, NPROD
                                 C(K,I) = CONU(K,I)
24                      CONTINUE
               ELSE
                        DEN(I) = DENL(I)
                        T(I) = TL(I)
                        DO 26 K = 1, NPROD
                                 C(K,I) = CONL(K,I)
26                      CONTINUE
               ENDIF
30    CONTINUE
C
C***   DELDEN IS DENSITY IMMEDIATELY ABOVE THE VENT LESS DENSITY
C***   DENSITY IMMEDIATELY BELOW THE VENT
C
      DELDEN = DEN(1) - DEN(2)
C
C***   3. CALCULATE VST(I), THE "STANDARD" VOLUME RATE OF FLOW
C***     THROUGH THE VENT INTO SPACE I
C
C***   CALCULATE VST(I) IF DELP = 0
C
      IF(DELP.EQ.0.0D0)THEN
               VST(1) = 0.0D0
```

```
              VST(2) = 0.0D0
        ENDIF
        IF(DELP.EQ.0.D0)     GOTO 32
C
C***    CALCULATE VST(I) FOR NONZERO DELP
C
        IF(DELP.GT.0.0D0)THEN
              VST(2) = 0.0D0
              RHO = DEN(2)
              EPS = DELP/P(2)
        ENDIF
        IF(DELP.LT.0.0D0)THEN
              VST(1) = 0.0D0
              RHO = DEN(1)
              EPS = -DELP/P(1)
        ENDIF
        X = 1.0D0 - EPS
        COEF = 0.60D0 + 0.25D0*EPS
        XO = 1.0D0
        EPSCUT = EPSP*MAX(XO,DPREF(1),DPREF(2))
        EPSCUT = DSQRT(EPSCUT)
        SRDELP = DSQRT(DABS(DELP))
        FNOISE = 1.0D0
        IF((SRDELP/EPSCUT).LE.130.D0)THEN
              FNOISE = 1.0D0 - DEXP(-SRDELP/EPSCUT)
C
C***    NOTE: IF SINGLE PRECISION THEN USED 65. INSTEAD OF 130.
C
        ENDIF
        IF(EPS.LE.0.1D-5)THEN
              W = 1.0D0 - 0.75D0*EPS/GAM
        ELSE
              IF(EPS.LT.GAMCUT)THEN
                    GG = X**(1.0D0/GAM)
                    FF = DSQRT((2.0D0*GAM/(GAM-1.0D0))*GG*GG*
     $                                    (1.0D0-X/GG))
              ELSE
                    FF = GAMMAX
              ENDIF
                    W = FF/DSQRT(EPS+EPS)
        ENDIF
        V = FNOISE*COEF*W*DSQRT(2.0D0/RHO)*AVENT*SRDELP
        IF(DELP.GT.0.0D0)VST(1) = V
        IF(DELP.LT.0.0D0)VST(2) = V
  32  CONTINUE
C
C***    4. WHEN CROSS-VENT DENSITY CONFIGURATION IS UNSTABLE, I.E.,
C***           DELDEN > 0, THEN CALCULATE THE VENT FLOW ACCORDING TO:
C***           COOPER, L.Y., COMBINED PRESSURE- AND BUOYANCY-DRIVEN FLOW
C***           THROUGH A HORIZONTAL VENT, TO APPEAR AS NISTIR, NATIONAL
C***           INSTITUTE OF STANDARDS AND TECHNOLOGY, GAITHERSBURG MD
C
C***    FOR STABLE CONFIGURATION, GO TO 5. AND VOLUME FLOW RATES WITH
C***    STANDARD MODEL
C
        IF(DELDEN.LE.0.0D0) GOTO 35
C
C***    FOR UNSTABLE CONFIGURATION, NOW CALCULATE THE COMBINED PRESSURE-
C***    AND BUOYANCY-DRIVEN VOLUME VENT FLOW RATES        FROM THE HIGH-TO-LOW
C***    AND      FROM THE LOW-TO-HIGH SIDES OF THE VENT, VBHIGH AND VBLOW,
C***    RESPECTIVELY. FROM THESE THEN CALCULATE THE COMBINED PRESSURE-
C***    AND BUOYANCY-DRIVEN VOLUME FLOW RATES, VB(I), THROUGH THE VENT
C***    INTO SPACE I.
C
        TBAR=(T(1)+T(2))/2.D0
        DENBAR=(DEN(1)+DEN(2))/2.D0
        XMEW=(0.04128D-7)*DENBAR*(TBAR**2.5D0)/(TBAR+110.4D0)
        EPSDEN=DELDEN/DENBAR
        D=DSQRT(4.D0*AVENT/PI)
```

```
      GR=2.D0*G*(D**3)*EPSDEN/((XMEW/DENBAR)**2.D0)
      IF(DELP.GT.0.D0) EPSDEN=-EPSDEN
      VHIGHFL=0.1754D0*AVENT*DSQRT(2.D0*G*D*DABS(EPSDEN))*
     1                                                   DEXP(0.5536D0*EPSDEN)
      DELPFL=0.2427D0*(4.D0*G*DABS(EPSDEN*DENBAR)*D)*(1.D0+EPSDEN/2.D0)*
     1                                                   DEXP(1.1072D0*EPSDEN)
      DPDDPFL=DABS(DELP)/DELPFL
      SIGMA1=FNOISE*COEF*W/0.1780D0
      IF(DPDDPFL.GE.1.D0)THEN
            VBLOW=0.D0
            VBHIGH=VHIGHFL*(1.D0-(SIGMA2**2.D0)+
     1                DSQRT(SIGMA2**4.D0+(SIGMA1**2.D0)* (DPDDPFL-1.D0)))
      ELSE
            VEXMAX=0.055D0*(4.D0/PI)*AVENT*DSQRT(G*D*DABS(EPSDEN))
            XM=(SIGMA1/SIGMA2)**2.D0-1.D0
            VBLOW=VEXMAX*(((1.D0+XM3/2.D0)*((1.D0-DPDDPFL)**2)-
     1                                      (2.D0+XM3/2.D0)*(1.D0-DPDDPFL))**2.D0)
            IF(DPDDPFL.EQ.0.D0)THEN
                  VBHIGH=VBLOW
            ELSE
                  VBHIGH=VBLOW+
     1      (XM-DSQRT(1.D0+(XM**2.D0-1.D0)*(1.D0-DPDDPFL)))*
     1                                      VHIGHFL/(XM-1.D0)
            ENDIF
      ENDIF
      IF(DELP.GT.0.D0)THEN
            VB(1)=VBHIGH
            VB(2)=VBLOW
      ELSE
            VB(1)=VBLOW
            VB(2)=VBHIGH
      ENDIF
C
C***  5. CALCULATE VVENT(I), THE VOLUME RATE OF FLOW THROUGH
C***  THE VENT INTO SPACE I
C
35    CONTINUE
      IF(DELDEN.LE.0.0D0)THEN
            VVENT(1) = VST(1)
            VVENT(2) = VST(2)
      ELSE
            IF((0.D0.LT.GR).AND.(GR.LT.2.D7))THEN
            VVENT(1)=VST(1)+(GR/2.D7)*(VB(1)-VST(1))
            VVENT(2)=VST(2)+(GR/2.D7)*(VB(2)-VST(2))
                  ELSE
                  VVENT(1)=VB(1)
                  VVENT(2)=VB(2)
            ENDIF
      ENDIF
C***  6. CALCULATE THE VENT FLOW PROPERTIES
C
      DENVNT(1) = DEN(2)*P(1)/P(2)
      DENVNT(2) = DEN(1)*P(2)/P(1)
      TVENT(1) = T(2)
      TVENT(2) = T(1)
      DO 50 K = 1, NPROD
            CVENT(K,1) = C(K,2)
            CVENT(K,2) = C(K,1)
50    CONTINUE
C
C***  7. CALCULATE THE VENT MASS FLOW RATES
C
      DO 60 I = 1,2
            XMVENT(I) = DENVNT(I)*VVENT(I)
60    CONTINUE
C
C***  8. CALCULATE THE REST OF THE VENT FLOW RATES
C
      DO 70 I=1,2
```

```
              QVENT(I) = XMVENT(I)*CP*TVENT(I)
              DO 65 K = 1, NPROD
                     PVENT(K,I) = XMVENT(I)*CVENT(K,I)
65            CONTINUE
70       CONTINUE
C
C***     9. CALCULATE THE RATE AT WHICH THE VENT FLOWS ADD MASS,
C***     ENTHALPY, AND PRODUCTS TO THE LAYERS OF THE SPACES FROM
C***     WHICH THEY ARE EXTRACTED. FIRST TREAT LAYERS OF SPACE 1
C***     (I=1, J=2) AND THEN SPACE 2 (I=2, J=1).
C
         DO 95 I = 1, 2
              IF (I.EQ.1)THEN
                     J = 2
              ELSE
                     J = 1
              ENDIF
              IF(((YVENT.EQ.YREF(I)).AND.((YLAY(I)-YREF(I)).LT.0.D0))
    $    .OR.((YVENT.EQ.YCEIL(I)).AND.((YCEIL(I)-YLAY(I))
    $                               .GT.0.D0)))THEN
                     XMU(I) = -XMVENT(J)
                     XML(I) = 0.0D0
                     QU(I) = -QVENT(J)
                     QL(I) = 0.0D0
                     DO 75 K = 1, NPROD
                            PU(K,I) = -PVENT(K,J)
                            PL(K,I) = 0.0D0
 75                  CONTINUE
                     IF(DABS(YREF(I)-YCEIL(I)).LT.0.0001D0)THEN
                            XML(I) = XMU(I)
                            QL(I) = QU(I)
                            DO 80 K = 1, NPROD
                                   PL(K,I) = PU(K,I)
 80                         CONTINUE
                     ENDIF
                     ELSE
                     XML(I) = -XMVENT(J)
                     XMU(I) = 0.0D0
                     QL(I) = -QVENT(J)
                     QU(I) = 0.0D0
                     DO 85 K = 1, NPROD
                            PL(K,I) = -PVENT(K,J)
                            PU(K,I) = 0.0D0
 85                  CONTINUE
                     IF(DABS(YREF(I)-YCEIL(I)).LT.0.0001D0)THEN
                            XMU(I) = XML(I)
                            QU(I) = QL(I)
                            DO 90 K = 1, NPROD
                                   PU(K,I) = PL(K,I)
 90                         CONTINUE
                     ENDIF
              ENDIF
 95      CONTINUE
         RETURN
         END
```

VENTCF2A - CALCULATION OF THE FLOW THROUGH A HORIZONTAL CEILING/FLOOR VENT CONNECTING TWO SPACES WITH "SMOOTHING" OF LAYER EXTRACTION RATES AT TIMES OF RELATIVELY THIN ADJACENT-VENT LAYERS

DESCRIPTION

Consider an instant of time during the simulation of a multi-room compartment fire environment. This algorithm calculates the flow of mass, enthalpy, oxygen, and other products of combustion through a horizontal vent located in a ceiling/floor partition common to any two inside rooms of the facility or between an inside room and the outside environment local to the vent. *VENTCF2A* is a modification of *VENTCF2* [1]. It provides special considerations for "smoothing" rates of layer extraction from the flow source room at times of relatively thin adjacent-vent layers. When used in a full zone model, and depending on the integration software for the particular model, the considerations in *VENTCF2A* eliminate singularities that may cause convergence problems in fire simulations at times when adjacent-vent layers are growing or shrinking from near-zero depths.

Depicted in Figure 1a is the vent and the two spaces when they are both inside rooms of a multi-room facility. Figures 1b and 1c depict the situation when the two spaces involve one inside room of the facility and one outside space, either above or below the room, in which is simulated the outside environment local to the vent.

As in Figure 1, designate the top space as space 1 and the bottom space as space 2. It is assumed that the temperature, density, concentration of oxygen and of other products of combustion of interest in the upper and lower layer of each inside room and in the environment local to the vent of an outside space are specified. Also specified in each inside room are: the elevation above the datum elevation of the floor, and the upper-layer/lower-layer interface; and the pressure at the floor above the specified datum pressure. Specified in an outside space are: a reference elevation above the datum elevation, and the pressure at this reference elevation above the specified datum pressure.

When the upper gas is less dense than the lower gas, i.e., the fluid configuration is stable, the flow through the vent is determined by a traditional orifice-type flow model. Then, flow is determined by the cross-vent pressure difference without any regard for buoyancy effects (see, e.g., [2] and [3]) and the present algorithm/subroutine is identical to that of *VENTCF* [4]. When the configuration is unstable and the upper gas is more dense than the lower gas, the effects of combined pressure and buoyancy forces can be significant. For example if the cross-vent pressure is relatively small, the unstable density configuration leads to an exchange-type of flow, with gas in the lower space rising into the upper space and gas from the upper space dropping into the lower space, where the flow rate from the high- to the low-pressure side of the vent is the larger of the two. Also, even when the cross-vent pressure difference large enough to produce uni-directional flow, the effect of buoyancy can be great enough to reduce significantly the flow rate from what it would be in the absence of a cross-vent density difference. In the present algorithm, for the case of unstable configurations the calculation of the flow between the two spaces is based on the theory developed and presented in [5].

For unstable density configurations, the model of [5] and, therefore, the *VENTCF2* and *VENTCF2A* algorithms/subroutines are for flow through a circular, shallow (i.e., small ratio of depth to diameter), horizontal vent. It is also expected that the model will give reasonable estimates of flow even for non-circular vents, provided the aspect ratio (maximum-to-minimum span) of a vent shape of interest is not too much different than 1. Indeed, one of the example calculations of [5], which includes comparisons with some relevant experimental data, provides limited support for the applicability of the model in the case of square vents. However, **USE OF *VENTCF2* AND *VENTCF2A* IN HIGH-ASPECT-RATIO AND/OR MODERATE-TO-LARGE-DEPTH VENT SCENARIOS IS NOT VALID** when cross-vent pressure differences are small-to-moderate compared to Δp_{FLOOD}. Results beyond those developed in [5] are required before the present work can be used for the latter types of vent shape.

The geometry and the conditions local to the vent which determine the characteristics of the vent flow are depicted in Figure 2. These include: the densities, ρ_1 and ρ_2, and the hydrostatic pressures, p_1 and p_2, at the elevation, but away from the immediate vicinity of the vent in the upper and lower spaces, respectively, and the area, A_V, and shape of the vent. Regarding the shape, at the present time results for horizontal vent flows are only available for circular or square vents. Other properties local to the vent and indicated in Figure 2 are T_1 and T_2, the absolute temperatures, $c_{O2,1}$ and $c_{O2,2}$, the concentrations of oxygen, and $c_{K,1}$ and $c_{K,2}$, K = 2 to N_{PROD}, the concentrations of a product of combustion K.

To simulate fire scenarios at times when vent flows are driven by arbitrarily high cross-vent pressure differences (i.e., when compressibility effects begin to be significant), whether for stable or unstable cross-vent density configurations, both *VENTCF2* and *VENTCF2A* implement the ideas introduced in reference [3] and implemented previously in the algorithm/subroutines *VENTHP* [6] and *VENTCF* [4]. Such high cross-vent pressure differences could occur, for example, in fire scenarios involving flows through cracks in otherwise hermetically-sealed fire compartments.

The feature which defines the diffence between *VENTCF2* and *VENTCF2A* is in the treatment of the source of the vent flow when the adjacent-vent layer in the source room is relatively thin. When the thickness of the vent-adjacent layer, δy, is large enough, it is assumed in *VENTCF2A* that the flow driven through the vent is extracted entirely from this layer. Unless $\delta y = 0$, this assumption is always made in the *VENTCL2* model/algorithm, i.e., independent of the size of δy. However, in *VENTCL2A*, when δy is smaller than some specified, non-zero, characteristic thickness, δ, the model/algorithm assumes that only the fraction $\delta y/\delta$ of the net volumetric rate of flow driven through the vent from the room is extracted from the vent-adjacent layer, the remaining fraction, $(1 - \delta y/\delta)$, being extracted from the far layer.

It is reasonable to take the characteristic thickness, δ, as being of the order of the characteristic span of the vent opening, taken as to equivalent vent diameter, $D = (4A_V/\pi)^{1/2}$, but never greater than a characteristic distance related to the height of the room, H, from which the flow is extracted. Here δ is taken to be $\delta = \min(D/2, H/2)$.

OUTPUT

$c_{O2,1}$ [$c_{O2,2}$]

Concentration of oxygen of the flow from the top [bottom] space as it enters the vent. [(kg of oxygen)/(kg of layer)]

$c_{K,1}$ [$c_{K,2}$]

Concentration of product K of the flow from the top [bottom] space as it enters the vent. [(unit of product K)/(kg of layer)]

$c_{VENT,O2,I}$; I = 1 or 2

Concentration of oxygen in the component of the vent flow entering space I, provided such vent flow component is non-zero, i.e., provided $\dot{M}_{VENT,I}$, is non-zero. [(kg of oxygen)/(kg of vent flow)]

$c_{VENT,K,I}$; I = 1 or 2; K = 2 to NPROD

Concentration of product of combustion K in the component of the vent flow entering space I, provided such vent flow component is nonzero, i.e., provided $\dot{M}_{VENT,I}$ is non-zero. [(unit of product)/(kg of vent flow)]

$\dot{M}_{U,I}$ [$\dot{M}_{L,I}$]; I = 1 or 2

If space I is an inside room: Rate at which mass is <u>added</u> to the upper [lower] layer of room I due to the vent flow component which enters the other space. Note that this will <u>always be negative</u>, since the layer which supplies the material flowing to the other space will always have mass <u>extracted</u> from it. [W]

If space I is an "outside room": $\dot{M}_{U,I}$ is the rate at which mass is <u>added</u> to space I due to the vent flow component which enters the other space (i.e., the inside room). Note that this will <u>always be negative</u>, since an outside space which supplies material flowing through the vent to an adjacent space will always have mass <u>extracted</u> from it. $\dot{M}_{L,I}$ is identical to $\dot{M}_{U,I}$. [W]

$\dot{M}_{VENT,I}$; I = 1 to 2

Mass flow rate of the vent flow component entering space I. [kg/s]

$\dot{P}_{O2,L,I}$ [$\dot{P}_{O2,U,I}$] ; I = 1 or 2

If space I is an inside room: Rate at which oxygen is <u>added</u> to the upper [lower] layer of room I due to the vent flow component which enters the other space. Note that this will <u>always be negative</u>, since the layer which supplies the material flowing through the vent to the other space will always have its convected oxygen <u>extracted</u> from it. [(kg of O_2)/s]

If space I is an "outside room": $\dot{P}_{O2,U,I}$ is the rate at which oxygen is <u>added</u> to space I due to the vent flow component which enters the other space (i.e., the inside room). Note that this will <u>always be negative</u>, since an outside space which supplies material flowing through the vent to an adjacent space will always have its convected oxygen <u>extracted</u> from it. $\dot{P}_{O2,L,I}$ is identical to $\dot{P}_{O2,U,I}$. [(kg of O_2)/s]

$\dot{P}_{O2,VENT,I}$; I = 1 to 2

Mass flow rate of oxygen of the vent flow component entering space I. [(kg of oxygen)/s]

$\dot{P}_{K,L,I}$ [$\dot{P}_{K,U,I}$]; K = 2 to N_{PROD}; I = 1 or 2

If space I is an inside room: Rate at which product of combustion K is <u>added</u> to the upper [lower] layer of room I due to the vent flow component which enters the other space. Note that this will <u>always be negative</u> since the layer which supplies the material flowing through the vent to the other space will always have its convected product of combustion K <u>extracted</u> from it. [(unit of product K)/s]

If space I is an "outside room": $\dot{P}_{K,U,I}$ is the rate at which product of combustion K is <u>added</u> to space I due to the vent flow component which enters the other space (i.e., the inside room). Note that this will <u>always be negative</u>, since an outside space which supplies material flowing through the vent to an adjacent space will always have the convected product of combustion K <u>extracted</u> from it. $\dot{P}_{K,L,I}$ is identical to $\dot{P}_{K,U,I}$. [(unit of product K)/s]

$\dot{P}_{K,VENT,I}$; I = 1 to 2; K = 2 to N_{PROD}

Flow rate of product of combustion K in the vent flow component entering space I. [(unit of product K)/s]

p_1 [p_2]

Absolute hydrostatic pressure in the top [bottom] space at the elevation of the vent. [Pa = kg/(m·s^2)]

$\dot{Q}_{U,I}$ [$\dot{Q}_{L,I}$]; I = 1 or 2

If space I is an inside room: Rate at which enthalpy added to the upper [lower] layer of room I due to the vent flow component which enters the other space. Note that this will always be negative, since the layer which supplies the material which flows to the other space will always have its convected enthalpy extracted from it. The enthalpy is based on the absolute temperature of the flow, $T_{VENT,I}$. [W]

If space I is an "outside room": $\dot{Q}_{U,I}$ is the rate at which enthalpy is added to space I due to the vent flow component which enters the other space (i.e., the inside room). Note that this will always be negative, since an outside space which supplies material which flows through the vent to an adjacent space will always have its convected enthalpy extracted from it. The enthalpy is based on the absolute temperature of the flow, $T_{U,I}$. $\dot{Q}_{L,I}$ is identical to $\dot{Q}_{U,I}$. [W]

$\dot{Q}_{VENT,I}$; I = 1 to 2

Total enthalpy flow rate in the vent flow component entering space I. This is based on the absolute temperature of the flow, $T_{VENT,I}$. [W]

T_1 [T_2]

Absolute temperature of the flow from the top [bottom] space as it enters the vent. [K]

$T_{VENT,I}$; I = 1 to 2

Absolute temperature of the vent flow component entering space I, provided such vent flow component is non-zero. [K]

Δp

$p_2 - p_1$, i.e., difference between the pressure in the bottom space, at the elevation of the vent, and the pressure in the top space, at the elevation of the vent. [Pa = kg/(m·s^2)]

ρ_1 [ρ_2]

Density of the flow from the top [bottom] space as it enters the vent. [kg/m$_3$]

$\rho_{VENT,I}$; I = 1 to 2

Density of the vent flow component entering space I, provided such vent flow component is nonzero. [kg/m^3]

INPUT

A_V

Area of the vent [m^2].

$c_{L,K,I}$ [$c_{U,K,I}$]; K = 2 to N_{PROD}; I = 1 or 2

If space I is an inside room: Concentration of product of combustion K in lower [upper] layer of room I if the volume of the lower [upper] layer is non-zero (if the lower [upper] layer volume is zero then the $c_{L,K,I}$ [$c_{U,K,I}$] value is not used in the calculation). [(unit of product K)/(kg of layer)]

If space I is an "outside room": $c_{L,K,I}$ is the uniform concentration throughout the space of product of combustion K; $c_{U,K,I}$ is specified as being identical to $c_{L,K,I}$. [(unit of product K)/(kg of local atmosphere)]

$c_{L,O2,I}$ [$c_{U,O2,I}$]; I = 1 or 2

If space I is an inside room: Concentration of oxygen in lower [upper] layer of room I if the volume of the lower [upper] layer is non-zero (if the lower [upper] layer volume is zero then the $c_{L,O2,I}$ [$c_{U,O2,I}$] value is not used in the calculation). [(kg of oxygen)/(kg of layer)]

If space I is an "outside room": $c_{L,O2,I}$ is the uniform concentration throughout the space of oxygen; $c_{U,O2,I}$ is specified as being identical to $c_{L,O2,I}$. [(kg of oxygen)/(kg of local atmosphere)]

C_p

Specific heat at constant pressure of the vent flow. [$W \cdot s/(kg \cdot K)$] (suggest 10^3 $W \cdot s/(kg \cdot K)$ for air as default)

N_{PMAX}

Maximum allowed number of products of combustion.

N_{PROD}

Number of products of combustion, including oxygen, being tracked in the simulation.

p_{DAT}

Datum absolute pressure. [$Pa = kg/(m \cdot s^2)$]

$T_{L,I}$ [$T_{U,I}$]; I = 1 or 2

If space I is an inside room: Absolute temperature of the lower [upper] layer in room I if the volume of the lower [upper] layer is non-zero (if the lower [upper] layer volume is zero then the $T_{L,I}$ [$T_{U,I}$] value is not used in the calculation). [K]

If space I is an "outside room": $T_{L,I}$ is the uniform absolute temperature there, taken to be the temperature at the reference elevation, $y_{REF,I}$; $T_{U,I}$ is specified as being identical to $T_{L,I}$. [K]

$y_{CEIL,I}$ [$y_{REF,I}$]

If space I is an inside room: Elevation of the ceiling [floor] of room I above the datum elevation. [m]

If space I is an "outside room": $y_{CEIL,I}$ and $y_{REF,I}$ are both identical and equal to the reference elevation of space I above the datum elevation, i.e., the specification must satisfy $y_{CEIL,I} \equiv y_{REF,I}$. The latter identity, which will never be satisfied for an inside room, is a characteristic of the input data used to distinguish an inside room from an "outside room." [m]

$y_{LAYER,I}$; I = 1 or 2

If space I is an inside room: Elevation of the upper/lower layer interface in room I above the datum elevation. [m]

If space I is an "outside room": $y_{LAYER,I}$ is specified as being identical to $y_{REF,I}$. [m]

y_{VENT}

Elevation of the vent above the datum elevation. Note that y_{VENT} must be identical to either $y_{CEIL,I}$ or $y_{REF,I}$ for each of the one or two inside rooms involved in the calculation. [m]

$\delta p_{REF,I}$; I = 1 or 2

Pressure at the reference elevation, $y_{REF,I}$, in space I above the datum absolute pressure, p_{DAT}. If space I is an inside room, then $\delta p_{REF,I}$ and $y_{REF,I}$ must correspond to the pressure and elevation, respectively, within the room and at the floor. [Pa = kg/(m·s^2)]

ε_p

Error tolerance for $\delta p_{REF,I}$. If $p_{ERROR,I}$ is defined as the uncertainty in $\delta p_{REF,I}$, I = 1 or 2, then $p_{ERROR,I}$ satisfies

$$|p_{ERROR,I}| < \varepsilon_p p_0 + |\delta p_{REF,I}| \varepsilon_p$$

where p_0 = 1.0Pa. The first term is based on an absolute error tolerance and dominates the above error bound when $|\delta p_{REF,I}|$ is less than 1.0Pa. The second term is a relative error tolerance and dominates when $|\delta p_{REF,I}|$ is greater than 1.0Pa. ε_p should be chosen to be consistent with the tolerance specified for the computation of $\delta p_{REF,I}$ terms in the overall compartment fire model computer code which uses this algorithm.

$\rho_{L,I}$ [$\rho_{U,I}$]; I = 1 or 2

If space I is an inside room: Density of the lower [upper] layer in room I if the volume of the lower [upper] layer is non-zero (if the lower [upper] layer volume is zero then the $\rho_{L,I}$ [$\rho_{U,I}$] value is not used in the calculation). [kg/m^3]

If space I is an "outside room": $\rho_{L,I}$ is the uniform density there; $\rho_{U,I}$ is specified as being identical to $\rho_{L,I}$. [kg/m^3]

CALCULATION

Set all output to zero. If $A_V = 0$ then calculation is complete, if not then:

1. Calculate p_I for $I = 1$ and 2, and then Δp (the p_I calculation follows the *DELP* algorithm/subroutine of reference [7]):

$$p_I = \delta p_{REF,I} + \delta p_I + p_{DAT} \tag{1}$$

$$\Delta p = p_2 - p_1 = (\delta p_{REF,2} - \delta p_{REF,1}) + (\delta p_2 - \delta p_1) \tag{2}$$

where

$$\text{if } y_{REF,I} \leq y_{VENT} \leq y_{LAYER,I} \text{ then: } \delta p_I = -\rho_{L,I} g(y_{VENT} - y_{REF,I})$$
$$\text{else: } \delta p_I = -\rho_{L,I} g(y_{LAYER,I} - y_{REF,I}) - \rho_{U,I} g(y_{VENT} - y_{LAYER,I}) \tag{3}$$

and where g, the acceleration of gravity, is 9.8 m/s^2.

2. Calculate D, δ_I, δy_I, ρ_I, T_I, $c_{O2,I}$, and the $c_{K,I}$, K = 2 to N_{PROD}, for I = 1 and 2, and then $\Delta\rho$:

$$D = (4A_V/\pi)^{1/2} \tag{4}$$

If $y_{CEIL,I} > y_{REF,I}$ then (space I is an inside space and)

$$\delta_I = \min[(y_{CEIL,I} - y_{REF,I})/2, D/2]; \quad \delta y_I = |y_{LAYER,I} - y_{VENT}|$$

else ($y_{CEIL,I} = y_{REF,I}$, space I is an outside space, and)

$$\delta_I = D/2; \quad \delta y_I = 0$$

If $\delta y_I > \delta_I$ then (vent flow from space I is extracted from the vent-adjacent layer):

If I = 1 (i.e., the upper room) then

$$\rho_1 = \rho_{L,I},\ T_1 = T_{L,1},\ c_{O2,1} = c_{L,O2,1}, \text{ and } c_{K,1} = c_{L,K,1}$$

else (I = 2, i.e., the lower room and)

$$\rho_2 = \rho_{U,2},\ T_2 = T_{U,2},\ c_{O2,2} = c_{U,O2,2}, \text{ and } c_{K,2} = c_{U,K,2}$$

else ($\delta y_I \leq \delta_I$ and the vent flow from space I is extracted from both layers)

If I = 1 (i.e., the upper room) then

$$\rho_1 = \rho_{U,1}(1 - \delta y_1/\delta_1) + \rho_{L,1}\delta y_1/\delta_1; \quad T_1 = T_{U,1}\rho_{U,1}/\rho_1;$$

$$c_{O2,1} = [c_{U,O2,1}\rho_{U,1}(1 - \delta y_1/\delta_1) + c_{L,O2,1}\rho_{L,1}\delta y_1/\delta_1]/\rho_1;$$

$$c_{K,1} = [c_{U,K,1}\rho_{U,1}(1 - \delta y_1/\delta_1) + c_{L,K,1}\rho_{L,1}\delta y_1/\delta_1]/\rho_1,\ K = 2, N_{PROD}$$

else (I = 2, i.e., the lower room and)

$$\rho_2 = \rho_{L,2}(1 - \delta y_2/\delta_2) + \rho_{U,2}\delta y_2/\delta_2;\ T_2 = T_{L,2}\rho_{L,2}/\rho_2;$$

$$c_{O2,2} = [c_{L,O2,2}\rho_{L,2}(1 - \delta y_2/\delta_2) + c_{U,O2,2}\rho_{U,2}\delta y_2/\delta_2]/\rho_2;$$

$$c_{K,2} = [c_{L,K,2}\rho_{L,2}(1 - \delta y_2/\delta_2) + c_{U,K,2}\rho_{U,2}\delta y_2/\delta_2]/\rho_2,\ K = 2, N_{PROD}$$

$$\Delta\rho = \rho_1 - \rho_2 \tag{5}$$

3. Define $\dot{V}_{ST,HIGH}$ as the volume rate of flow through the vent, from the high- to the low-pressure space, that is predicted with a "standard," unidirectional-flow-type calculation (i.e., without regard to the effect of buoyancy, in general, or the stability of the cross-vent density configuration, in particular), where arbitrarily high cross-vent pressures are allowed. Here, the calculation follows the model of [3] as implemented in the *VENTHP* algorithm/subroutine of [6]. Calculate $\dot{V}_{ST,HIGH}$:

If $\Delta p = 0$ then: $\dot{V}_{ST,HIGH} = 0$; skip to (the next) item 4 of the **CALCULATION** (6)

If $\Delta p > 0$ or $\Delta p < 0$ then:

a. Define and compute ρ_{HIGH}, ε, and x:

If $\Delta p > 0$, i.e., "standard" flow from (lower) space 2 to (upper) space 1, then:

$$\rho_{HIGH} = \rho_2;\ \varepsilon = \Delta p/p_2 \tag{7}$$

If $\Delta p < 0$, i.e., "standard" flow from (upper) space 1 to (lower) space 2, then:

$$\rho_{HIGH} = \rho_1;\ \varepsilon = -\Delta p/p_1 \tag{8}$$

$$x = 1 - \varepsilon \tag{9}$$

b. Compute C(x), the vent flow coeffient, and w(x):

$$C(x) = 0.85 - 0.25x = 0.60 + 0.25\varepsilon \tag{10}$$

$$w(x) = \begin{cases} 1 - [3/(4\gamma)]\varepsilon & \text{if } 0 < \varepsilon \le 10^{-5} \\ f(x)/[2\varepsilon]^{1/2} & \text{if } 1 \ge \varepsilon > 10^{-5} \end{cases} \tag{11}$$

where

$$f(x) = \begin{cases} \{[2\gamma/(\gamma - 1)]x^{2/\gamma}[1 - x^{(\gamma - 1)/\gamma}]\}^{1/2} & \text{if } \varepsilon < 1 - [2/(\gamma + 1)]^{\gamma/(\gamma - 1)} \\ \{\gamma[2/(\gamma + 1)]^{(\gamma + 1)/(\gamma - 1)}\}^{1/2} & \text{if } \varepsilon \ge 1 - [2/(\gamma + 1)]^{\gamma/(\gamma - 1)} \end{cases} \tag{12}$$

and where γ, the ratio of specific heats of the vent flow gas, is taken to be that of air, 1.40. Note that for the present horizontal vent application, the C(x) of Eq. (10) is taken to be consistent with the standard incompressible limit for flow through circular sharp-edged orifices in the sense that $C \rightarrow 0.60$ as $\varepsilon \rightarrow 0$ [8].

c. Define and compute $\Delta p_{CUT}^{1/2}$:

$$\Delta p_{CUT}^{1/2} \equiv [\varepsilon_p \mathrm{MAX}(1.0\mathrm{Pa}, |\delta p_{REF,1}|, |\delta p_{REF,2}|)]^{1/2} \tag{13}$$

d. Define and compute F_{NOISE}, a numerical damping factor, and then $\dot{V}_{ST,HIGH}$:

$$F_{NOISE} = 1.0 - \exp(-|\Delta p|^{1/2}/\Delta p_{CUT}^{1/2}) \tag{14}$$

$$\dot{V}_{ST,HIGH} = F_{NOISE}C(x)w(x)(2/\rho_{HIGH})^{1/2}A_V|\Delta p|^{1/2} \tag{15}$$

The term F_{NOISE} of Eq. (14) is designed to damp out the numerical noise (error) in the calculated value for Δp that would otherwise be dominant in Eq. (15) when Δp is small relative to the maximum of 1.0 pascal and the calculated reference pressures, $\delta p_{REF,1}$, $\delta p_{REF,2}$. The term Δp_{CUT} of Eq. (13) is an estimate of how small the maximum of $|\Delta p|$ must be to retain a few digits of accuracy in the calculation of Δp. When the calculated value of $|\Delta p|$ is smaller than p_{CUT}, this value and, therefore, the value of $\dot{V}_{ST,HIGH}$ in Eq. (15) will likely contain noise which should be damped. F_{NOISE} is constructed to tend towards 1 when $|\Delta p|$ is large relative to Δp_{CUT} and tends towards 0 when $|\Delta p|$ is small relative to Δp_{CUT}.

4. When the cross-vent density configuration is unstable ($\Delta\rho > 0$), mixed pressure- and buoyancy-driven aspects of the flow have to be considered and the vent flow rates are calculated according to [5]. Define $\dot{V}_{B,HIGH}$, $\dot{V}_{B,LOW}$ as the reference-[5], buoyancy-affected, volume flow rates across the vent from the high-to-low and low-to-high pressure spaces, respectively.

If $\Delta\rho \leq 0$: $\dot{V}_{B,HIGH} = \dot{V}_{B,LOW} = 0$; skip to (the next) item 5 of the **CALCULATION** (17)

a. Calculate $\bar{T}$, $\bar{\rho}$, $\mu(\bar{T})$ in m^2/s from [12], and $\varepsilon > 0$:

$$\bar{T} = (T_1 + T_2)/2;\ \bar{\rho} = (\rho_1 + \rho_2)/2;\ \mu(\bar{T}) = \bar{\rho}[0.04128(10^{-7})\bar{T}^{5/2}/(\bar{T} + 110.4)];$$

$$\varepsilon = \Delta\rho/\bar{\rho} > 0 \tag{18}$$

b. Calculate $\bar{G}r$; if $p_2 > p_1$, i.e., $\Delta p > 0$, then replace ε by $-\varepsilon < 0$:

$$\bar{G}r = 2gD^3|\varepsilon|/[\mu(\bar{T})/\bar{\rho}]^2;\ \text{if } \Delta p > 0 \text{ then } \varepsilon = -\varepsilon \tag{19}$$

c. Calculate conditions at the limit of unidirectional flow (i.e., the flooding condition) and the relative pressure, δp^*:

$$\dot{V}_{HIGH,FLOOD} = 0.1754A_V(2gD|\varepsilon|)^{1/2}\exp(0.5536\varepsilon);$$

$$\Delta p_{FLOOD} = 0.2427(4g\Delta\rho D)(1 + \varepsilon/2)\exp(1.1072\varepsilon); \tag{20}$$

$$\delta p^* = |\Delta p|/\Delta p_{FLOOD}$$

d. Calculate σ_1, σ_2 and then $V_{B,LOW}$, $V_{B,HIGH}$:

$$\sigma_1 = F_{NOISE}C(x)w(x)/0.1780;\ \sigma_2 = 1.045 \tag{21}$$

If $\delta p^* \geq 1$, expect uni-directional flow:

$$V_{B,LOW} = 0;\ \dot{V}_{B,HIGH} = \dot{V}_{HIGH,FLOOD}\{1 - \sigma_2^2 + [\sigma_2^4 + \sigma_1^2(\delta p^* - 1)]^{1/2}\} \tag{22}$$

If $\delta p^* < 1$, expect mixed flow:

$$\dot{V}_{EX,MAX} = 0.055(4/\pi)A_V(gD|\varepsilon|)^{1/2};\ \ m_3 = -0.7070;\ \ M = (\sigma_1/\sigma_2)^2 - 1 \tag{23}$$

$$\begin{aligned}\dot{V}_{B,LOW} &= \dot{V}_{EX,MAX}[(1 + m_3/2)(1 - \delta p^*)^2 - (2 + m_3/2)(1 - \delta p^*)]^2 \\ \dot{V}_{B,HIGH} &= \dot{V}_{B,LOW} + \{M - [1 + (M^2 - 1)(1 - \delta p^*)]^{1/2}\}\dot{V}_{HIGH,FLOOD}/(M - 1)\end{aligned} \tag{24}$$

(Note: σ_1 of Eq. (21) is somewhat different than σ_1 in [5]. The modification here is provide for an analytic representation of vent flow which is continuous and uniformly valid even as δp^* is increased to a level where compressibility effects become important. The result of [5] does not include the effect of compressibility.)

5. Following [5], when $\Delta\rho > 0$ the above will be taken as the flow solution provided $\bar{G}r \geq 2(10^7)$. For smaller $\bar{G}r$, the reference-[5] solution begins to loose its validity, and there is no existing model for the flows the range $0 < \bar{G}r < 2(10^7)$. However, it is clear that the above-calculated "standard" flow must be approached as $\bar{G}r \rightarrow 0$.

Consistent with the above comments, when $\bar{G}r$ is in the range $0 \leq \bar{G}r < 2(10^7)$, the vent flow will be estimated by:

flow = ("standard" flow) + [(reference-[5] flow) - ("standard" flow)]$\bar{G}r/[2(10^7)]$

a. Define $\dot{V}_{HIGH}$ and $\dot{V}_{LOW}$ as volume flow rates across the vent from the high-to-low and low-to-high pressure spaces, respectively.

$$\text{If } \Delta\rho \leq 0:\ \ \dot{V}_{HIGH} = \dot{V}_{ST,HIGH};\ \ \dot{V}_{LOW} = 0 \tag{25}$$

If $\Delta\rho > 0$ and $0 < \bar{G}r < 2(10^7)$:

$$\begin{aligned}\dot{V}_{HIGH} &= \dot{V}_{ST,HIGH} + (\dot{V}_{B,HIGH} - \dot{V}_{ST,HIGH})\bar{G}r/[2(10^7)] \\ \dot{V}_{LOW} &= \dot{V}_{B,LOW}\bar{G}r/[2(10^7)]\end{aligned} \tag{26}$$

$$\text{If } \Delta\rho > 0 \text{ and } \bar{G}r \geq 2(10^7):\ \ \dot{V}_{HIGH} = \dot{V}_{B,HIGH};\ \ \dot{V}_{LOW} = \dot{V}_{B,LOW} \tag{27}$$

b. Define and calculate $\dot{V}_{VENT,I}$, I = 1 and 2, as the vent volume flow rate entering space I.

$$\text{If } \Delta p \geq 0:\ \ \dot{V}_{VENT,1} = \dot{V}_{HIGH};\ \dot{V}_{VENT,2} = \dot{V}_{LOW} \tag{28}$$

(i.e., flow to the upper space is the flow from the high- to the low-pressure space, and flow to the lower space is the flow from the low- to the high-pressure space)

$$\text{If } \Delta p < 0:\ \ \dot{V}_{VENT,1} = \dot{V}_{LOW};\ \dot{V}_{VENT,2} = \dot{V}_{HIGH} \tag{29}$$

(i.e., flow to the upper space is the flow from the low- to the high-pressure space, and flow to the lower space is the flow from the high- to the low-pressure space)

6. Calculate the vent flow properties $\rho_{VENT,I}$, $T_{VENT,I}$, $c_{VENT,O2,I}$, $c_{VENT,K,I}$, K = 2 to N_{PROD}, I = 1 and 2:

$$\rho_{VENT,1} = \rho_2(p_1/p_2),\ \rho_{VENT,2} = \rho_1(p_2/p_1);\ \ T_{VENT,1} = T_2,\ T_{VENT,2} = T_1; \tag{30}$$

$$c_{VENT,O2,1} = c_{O2,2},\ c_{VENT,O2,2} = c_{O2,1};\ c_{VENT,K,1} = c_{K,2},\ c_{VENT,K,2} = c_{K,1},\ K = 2 \text{ to } N_{PROD}$$

7. Calculate the vent flow rates $\dot{M}_{VENT,I}$, $I = 1$ and 2:

$$\dot{M}_{VENT,I} = \rho_{VENT,I}\dot{V}_{VENT,I} \tag{31}$$

8. Calculate the vent flow rates $\dot{Q}_{VENT,I}$, $\dot{P}_{O2,VENT,I}$, $\dot{P}_{K,VENT,I}$, $K = 2$ to N_{PROD}, $I = 1$ and 2:

$$\dot{Q}_{VENT,I} = \dot{M}_{VENT,I}C_pT_{VENT,I};\ \dot{P}_{O2,VENT,I} = \dot{M}_{VENT,I}c_{VENT,O2,I}; \tag{32}$$

$$\dot{P}_{K,VENT,I} = \dot{M}_{VENT,I}c_{VENT,K,I},\ K = 2 \text{ to } N_{PROD}$$

9. Calculate rates at which flows are added to layers of each space as a result of the vent flow extracted from it. First consider space 1 ($I = 1$, $J = 2$) and then space 2 ($I = 2$, $J = 1$). For either case:

If $\delta y_I > \delta_I$ then (vent flow from space I is extracted from the vent-adjacent layer):

If $I = 1$ (i.e., the upper room) then

$$\dot{M}_{L,1} = -\dot{M}_{VENT,2},\ \dot{M}_{U,1} = 0;\ \dot{Q}_{L,1} = -\dot{Q}_{VENT,2},\ \dot{Q}_{U,1} = 0;$$

$$\dot{P}_{O2,L,1} = -\dot{P}_{O2,VENT,2},\ \dot{P}_{O2,U,1} = 0;$$

$$\dot{P}_{K,L,1} = -\dot{P}_{K,VENT,2},\ \dot{P}_{K,U,1} = 0,\ K = 2,\ N_{PROD} \tag{33}$$

If $y_{CEIL,1} = y_{REF,1}$ then (room 1 is an outside room and)

$$\dot{M}_{U,1} = \dot{M}_{L,1};\ \dot{Q}_{U,1} = \dot{Q}_{L,1};$$

$$\dot{P}_{O2,U,1} = \dot{P}_{O2,L,1};\ \dot{P}_{K,U,1} = \dot{P}_{K,L,1},\ K = 2,\ N_{PROD}$$

else ($I = 2$, i.e., the lower room and)

$$\dot{M}_{U,2} = -\dot{M}_{VENT,1},\ \dot{M}_{L,2} = 0;\ \dot{Q}_{U,2} = -\dot{Q}_{VENT,1},\ \dot{Q}_{L,2} = 0;$$

$$\dot{P}_{O2,U,2} = -\dot{P}_{O2,VENT,1},\ \dot{P}_{O2,L,2} = 0;$$

$$\dot{P}_{K,U,2} = -\dot{P}_{K,VENT,1},\ \dot{P}_{K,L,2} = 0,\ K = 2,\ N_{PROD} \tag{34}$$

If $y_{CEIL,2} = y_{REF,2}$ then (room 2 is an outside room and)

$$\dot{M}_{U,2} = \dot{M}_{L,2};\ \dot{Q}_{U,2} = \dot{Q}_{L,2};$$

$$\dot{P}_{O2,U,2} = \dot{P}_{O2,L,2};\ \dot{P}_{K,U,2} = \dot{P}_{K,L,2},\ K = 2,\ N_{PROD}$$

else ($\delta y_I \leq \delta_I$ and the vent flow from space I is extracted from both layers)

If $I = 1$ (i.e., the upper room) then

$$\dot{M}_{U,1} = -\rho_{U,1}(1 - \delta y_1/\delta_1)\dot{V}_{VENT,2};\ \dot{M}_{L,1} = -\rho_{L,1}(\delta y_1/\delta_1)\dot{V}_{VENT,I}$$

$$\dot{Q}_{U,1} = \dot{M}_{U,1}C_pT_{U,1};\ \ \dot{Q}_{L,1} = \dot{M}_{L,1}C_pT_{L,1}$$

$$\dot{P}_{O2,U,1} = \dot{M}_{U,1}c_{U,O2,1};\ \ \dot{P}_{O2,L,1} = \dot{M}_{L,1}c_{L,O2,1}$$

$$\dot{P}_{K,U,1} = \dot{M}_{U,1}c_{U,K,1};\ \ \dot{P}_{K,L,1} = \dot{M}_{L,1}c_{L,K,1};\ K = 2,\ N_{PROD} \tag{35}$$

If $y_{CEIL,1} = y_{REF,1}$ then (room 1 is an outside room and)

$$\dot{M}_{L,1} = \dot{M}_{U,1};\ \ \dot{Q}_{L,1} = \dot{Q}_{U,1};$$

$$\dot{P}_{O2,L,1} = \dot{P}_{O2,U,1};\ \ \dot{P}_{K,L,1} = \dot{P}_{K,U,1},\ K = 2,\ N_{PROD}$$

else (I = 2, i.e., the lower room and)

$$\dot{M}_{L,2} = -\rho_{L,2}(1 - \delta y_2/\delta_2)\dot{V}_{VENT,1};\ \ \dot{M}_{U,2} = -\rho_{U,2}(\delta y_2/\delta_2)\dot{V}_{VENT,1};$$

$$\dot{Q}_{L,2} = \dot{M}_{L,2}C_pT_{L,2};\ \ \dot{Q}_{U,2} = \dot{M}_{U,21}C_pT_{U,2};$$

$$\dot{P}_{O2,L,2} = \dot{M}_{L,2}c_{L,O2,2};\ \ \dot{P}_{O2,U,2} = \dot{M}_{U,2}c_{U,O2,2};$$

$$\dot{P}_{K,L,2} = \dot{M}_{L,2}c_{L,K,2};\ \dot{P}_{K,U,2} = \dot{M}_{U,2}c_{U,K,2};\ K = 2,\ N_{PROD}; \tag{36}$$

If $y_{CEIL,2} = y_{REF,2}$ then (room 2 is an outside room and)

$$\dot{M}_{U,2} = \dot{M}_{L,2};\ \ \dot{Q}_{U,2} = \dot{Q}_{L,2};$$

$$\dot{P}_{O2,U,2} = \dot{P}_{O2,L,2};\ \ \dot{P}_{K,U,2} = \dot{P}_{K,L,2},\ K = 2,\ N_{PROD}$$

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[6] Cooper, L.Y. and Forney, G.P., "*VENTHP* - Calculation of the Flow of Mass, Enthalpy, Oxygen, and Other Products of Combustion Through a Vertical Constant-Width Vent in a Wall Segment Common to Two Rooms;" an entry in: "Consolidated Compartment Fire Model (CCFM) Computer Code Application CCFM.VENTS - Part III: Algorithms and Subroutines," Cooper, L.Y., and Forney, G.P., Editors, NISTIR 4344, National Institute of Standards and Technology, July 1990.

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[8] Shapiro, A.H., The Dynamics and Thermodynamics of Commpressible Fluid Flow: Volume 1, Roland Press, New York, p. 100, 1953.

SUBROUTINE VARIABLES

All nomenclature in the subroutine is identical to the nomenclature used above except for:

A_V	-	AVENT [m^2]
C	-	COEF
C_p	-	CP [W·s/(kg·K)]
$c_{L,K,I}$, $c_{U,K,I}$	-	CONL(K,I), CONU(K,I), I = 1 or 2 [(unit of product K)/(kg of layer)]
$c_{L,O2,I}$, $c_{U,O2,I}$	-	CONL(1,I), CONU(1,I), I = 1 or 2 [(kg of oxygen)/(kg of layer)]
$c_{VENT,K,I}$	-	CVENT(K,I), I= 1 or 2 [(unit of product K)/(kg of vent flow)
$c_{VENT,O2,I}$	-	CVENT(1,I), I = 1 or 2 [(kg of oxygen)/(kg of vent flow)]
$c_{K,I}$	-	C(K,I), I= 1 or 2 [(unit of product K)/(kg of vent flow)
$c_{O2,I}$	-	C(1,I), I = 1 or 2 [(kg of oxygen)/(kg of vent flow)]
F_{NOISE}	-	FNOISE [dimensionless]
f	-	FF [dimensionless]
$\bar{G}r$	-	GR [dimensionless]
g	-	9.8 m/s^2
M	-	XM [dimensionless]
$\dot{M}_{L,I}$, $\dot{M}_{U,I}$	-	XML(I), XMU(I), I = 1 or 2 [kg/s]

$\dot{M}_{VENT,I}$	-	XMVENT(I), I = 1 or 2 [kg/s]
m_3	-	XM3 [dimensionless]
N_{PMAX}	-	NPMAX [dimensionless]
N_{PROD}	-	NPROD [dimensionless]
$\dot{P}_{K,L,I}$, $\dot{P}_{K,U,I}$	-	PL(K,I), PU(K,I), I = 1 or 2 [(unit of product K)/s]
$\dot{P}_{K,VENT,I}$	-	PVENT(K,I), I = 1 or 2 [(unit of product K)/s]
$\dot{P}_{O2,L,I}$, $\dot{P}_{O2,U,I}$	-	PL(1,I), PU(1,I), I = 1 or 2 [(kg of oxygen)/s]
$\dot{P}_{O2,VENT,I}$	-	PVENT(1,I), I = 1 or 2 [(kg of oxygen)/s]
p_{DAT}	-	PDATUM [Pa = kg/(m·s^2)]
p_I	-	P(I), I = 1 or 2 [Pa = kg/(m·s^2)]
$\dot{Q}_{L,I}$, $\dot{Q}_{U,I}$	-	QL(I), QU(I), I = 1 or 2 [W]
$\dot{Q}_{VENT,I}$	-	QVENT(I), I = 1 or 2 [W]
$\bar{T}$	-	TBAR [K]
T_I	-	T(I), I = 1 or 2 [K]
$T_{L,I}$, $T_{U,I}$	-	TL(I), TU(I), I = 1 or 2 [K]
$T_{VENT,I}$	-	TVENT(I), I = 1 or 2 [K]
$\dot{V}_{B,HIGH}$	-	VBHIGH = VB(1) if $\Delta p \geq 0$, = VB(2) if $\Delta p \leq 0$ [m^3/s]
$\dot{V}_{B,LOW}$	-	VBLOW = VB(2) if $\Delta p \geq 0$, = VB(1) if $\Delta p \leq 0$ [m^3/s]
$\dot{V}_{EX,MAX}$	-	VEXMAX [m^3/s]
$\dot{V}_{HIGH}$, $\dot{V}_{LOW}$	-	VHIGH, VLOW [m^3/s]
$\dot{V}_{HIGH,FLOOD}$	-	VHIGHFL [m^3/s]
$\dot{V}_{ST,HIGH}$	-	V = VST(1) if $\Delta p > 0$, = VST(2) if $\Delta p < 0$ [m^3/s]
$\dot{V}_{VENT,I}$	-	VVENT(I), I = 1 or 2 [m^3/s]
w	-	W [dimensionless]
x	-	X [dimensionless]
$y_{CEIL,I}$	-	YCEIL(I), I = 1 or 2 [m]

$y_{LAYER,I}$	-	YLAY(I), I = 1 or 2 [m]
$y_{REF,I}$	-	YREF(I), I = 1 or 2 [m]
y_{VENT}	-	YVENT [m]
γ	-	1.40
Δp	-	DELP [Pa = kg/(m·s²)]
$\Delta p_{CUT}^{1/2}$	-	DPC1D2 [Pa = kg/(m·s²)]
Δp_{FLOOD}	-	DELPFD [Pa = kg/(m·s²)]
$\Delta \rho$	-	DELDEN [kg/m³]
δ_I	-	DEL(I), I = 1 or 2 [m]
δp_*	-	DPDDPFL [Pa = kg/(m·s²)]
δp_I	-	DP(I), I = 1 or 2 [Pa = kg/(m·s²)]
$\delta p_{REF,I}$	-	DPREF(I), I = 1 or 2 [Pa = kg/(m·s²)]
δy_I	-	DELY(I), I = 1 or 2 [m]
ε	-	EPS [dimensionless]
ε_p	-	EPSP [dimensionless]
μ	-	XMEW [m²/s]
ρ_{HIGH}	-	DENHIGH [kg/m³]
$\bar{\rho}$	-	DENBAR [kg/m³]
ρ_I	-	DEN(I), I = 1 or 2 [kg/m³]
$\rho_{L,I}$, $\rho_{U,I}$	-	DENL(I), DENU(I), I = 1 or 2 [kg/m³]
$\rho_{VENT,I}$	-	DENVNT(I), I = 1 or 2 [kg/m³]
σ_1	-	SIGMA1 [dimensionless]
σ_2	-	SIGMA2 [dimensionless]

PREPARED BY

Leonard Y. Cooper
December 1993

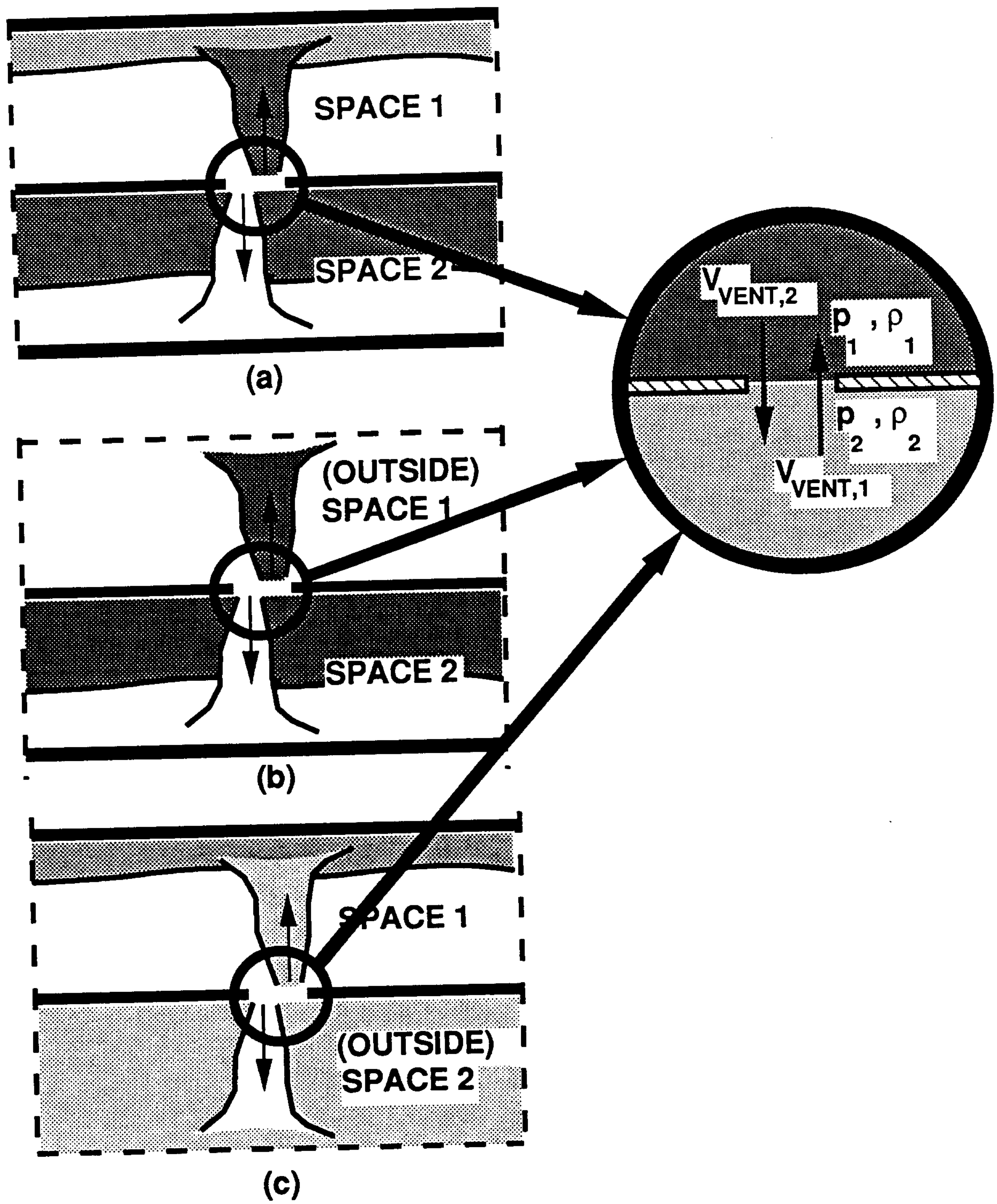

Figure 1. The possible configurations of the two spaces joined by a horizontal ceiling/floor vent with space 1 above space 2: a) two inside rooms; b) an outside space above an inside room; c) an inside room over an outside space.

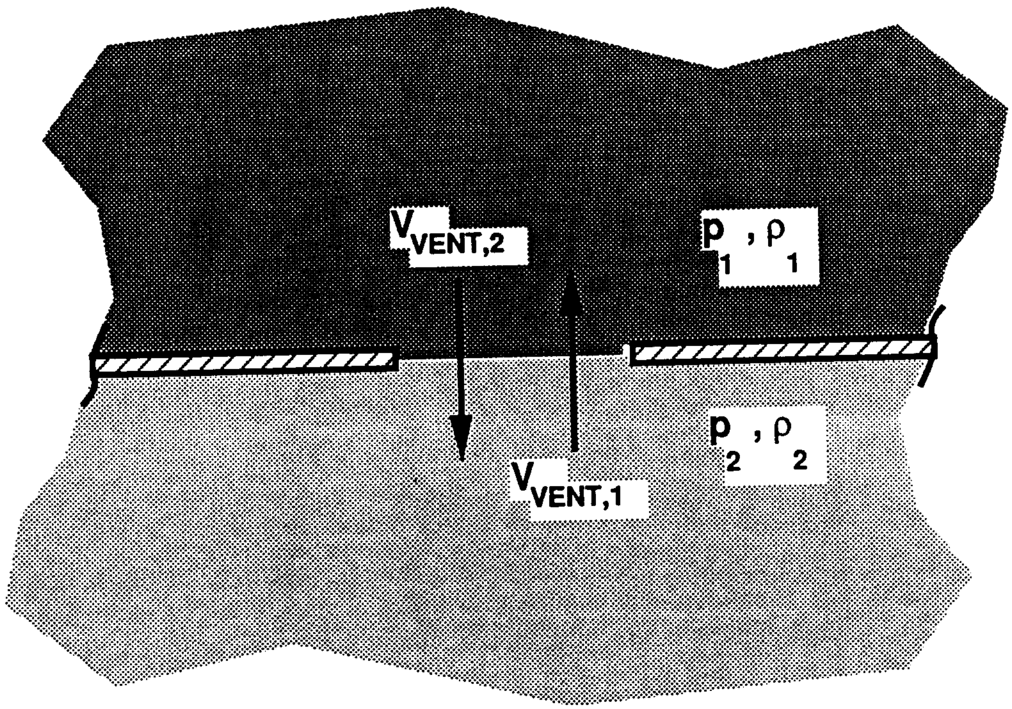

Figure 2. **The geometry and conditions local to a horizontal ceiling/floor vent which determine the characteristics of the vent flow.**

SUBROUTINE VENTCF2A

```
      SUBROUTINE VENTCF2A(
     I     AVENT,CONL,CONU,CP,NPMAX,NPROD,PDATUM,TL,TU,
     I     YCEIL,YREF,YLAY,YVENT,DPREF,EPSP,DENL,DENU,
     O     C,CVENT,XML,XMU,XMVENT,PL,PU,PVENT,P,QL,QU,QVENT,T,TVENT,
     O     FRACM,FRACQ,FRACP,
     O     DELP,DEN,DENVNT)
     INCLUDE PRECIS.INC
C*BEG
C*** VENTCF2A - CALCULATION OF THE FLOW OF MASS, ENTHALPY, OXYGEN
C              AND OTHER PRODUCTS OF COMBUSTION THROUGH A HORIZONTAL
C              VENT JOINING AN UPPER SPACE 1 TO A LOWER SPACE 2. THE
C              SUBROUTINE USES INPUT DATA DESCRIBING THE TWO-LAYER
C              ENVIRONMENT OF INSIDE ROOMS AND THE UNIFORM
C              ENVIRONMENT IN OUTSIDE SPACES. THIS IS A VARIATION
C              OF VENTCF2 WHICH SMOOTHS THE RATE OF EXTRACTION FROM
C              VENT-ADJACENT LAYERS WHEN SUCH LAYERS ARE RELATIVELY
C              THIN.
C
C*** SUBROUTINE ARGUMENTS
C
C  INPUT
C  -----
C  AVENT        -     AREA OF THE VENT [M**2]
C  CONL(K,I)    -     CONCENTRATION OF PRODUCT K IN LOWER LAYER OF AN INSIDE
C                     ROOM I OR UNIFORM CONCENTRATION OF PRODUCT K IN AN
C                     OUTSIDE SPACE I [(UNIT OF PRODUCT)/(KG LAYER)]
C  CONL(K,I)    -     CONCENTRATION OF PRODUCT K IN UPPER LAYER OF AN INSIDE
C                     ROOM I OR UNIFORM CONCENTRATION OF PRODUCT K IN AN
C                     OUTSIDE SPACE I [(UNIT OF PRODUCT)/(KG LAYER)]
C  CP           -     SPECIFIC HEAT [W*S/(KG*K)]
C  NPMAX        -     MAXIMUM ALLOWED NUMBER OF PRODUCTS
C  NPROD        -     NUMBER OF PRODUCTS IN CURRENT SCENARIO
C  PDATUM       -     DATUM ABSOLUTE PRESSURE [PA = KG/(M*S**2)]
C  TL(I)        -     TEMPERATURE OF LOWER LAYER OF AN INSIDE ROOM I OR
C                     TEMPERATURE OF AN OUTSIDE SPACE I [K]
C  TU(I)        -     TEMPERATURE OF UPPER LAYER OF AN INSIDE ROOM I OR
C                     TEMPERATURE OF AN OUTSIDE SPACE I [K]
C  YCEIL(I)     -     HEIGHT OF CEILING ABOVE DATUM ELEVATION FOR AN INSIDE
C                     ROOM I OR YREF(I) FOR AN OUTSIDE SPACE I [M]
C  YREF(I)      -     HEIGHT OF REFERENCE ELEVATION FOR SPACE I ABOVE DATUM
C                     ELEVATION [M]
C  YLAY(I)      -     HEIGHT OF LAYER ABOVE DATUM ELEVATION FOR AN INSIDE
C                     ROOM I OR YREF(I) FOR AN OUTSIDE SPACE I [M]
C  YVENT        -     HEIGHT OF VENT ABOVE DATUM ELEVATION [M]
C  DPREF(I)     -     PRESSURE IN SPACE I AT ITS REFERENCE ELEVATION ABOVE
C                     DATUM ABSOLUTE PRESSURE [PA = KG/(M*S**2)]
C  EPSP         -     ERROR TOLERANCE FOR DPREF [DIMENSIONLESS]
C  DENL(I)      -     DENSITY OF LOWER LAYER OF AN INSIDE ROOM I OR DENSITY
C                     OF AN OUTSIDE SPACE I [KG/M**3]
C  DENU(I)      -     DENSITY OF UPPER LAYER OF AN INSIDE ROOM I OR DENSITY
C                     OF AN OUTSIDE SPACE I [KG/M**3]
C
C
C  OUTPUT
C  ------
C  C(K,I)       -     CONCENTRATION OF EACH PRODUCT IMMEDIATELY ABOVE (IN
C                     SPACE I = 1) AND BELOW (IN SPACE I = 2) THE VENT
C                     [(UNIT OF PRODUCT)/(KG LAYER)]
C  CVENT(I)     -     CONCENTRATION OF EACH PRODUCT IN THE VENT FLOW
C                     COMPONENT ENTERING SPACE I [(UNIT OF PRODUCT)/(KG OF
C                     VENT FLOW)]
C  FRACM(I)     -     FRACTION OF XMVENT(I) EXTRACTED FROM NEAR-VENT LAYER
C                     OF SUPPLY ROOM
C  FRACQ(I)     -     FRACTION OF QVENT(I) EXTRACTED FROM NEAR-VENT LAYER
C                     OF SUPPLY ROOM
C  FRACP(K,I)   -     FRACTION OF PVENT(K,I) EXTRACTED FROM NEAR-VENT LAYER
C                     OF SUPPLY ROOM
C  XML(I)       -     RATE AT WHICH MASS IS ADDED TO THE LOWER LAYER OF AN
```

```
C                              INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I =
C                              1 (I = 2) DUE TO THE VENT FLOW COMPONENT ENTERING
C                              SPACE = 2 (I = 1) [KG/S]
C  XMU(I)            -         RATE AT WHICH MASS IS ADDED TO THE UPPER LAYER OF AN
C                              INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I = 1
C                              (I = 2) DUE TO THE VENT FLOW COMPONENT ENTERING SPACE
C                              I = 2 (I = 1) [KG/S]
C  XMVENT(I)         -         MASS FLOW RATE IN THE VENT FLOW COMPONENT ENTERING
C                              SPACE I [KG/S]
C  PL(K,I)           -         RATE AT WHICH PRODUCT K IS ADDED TO THE LOWER LAYER OF
C                              AN INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I
C                              = 1 (I = 2) DUE TO THE VENT FLOW CONPONENT ENTERING
C                              SPACE I = 2 (I = 1) [(UNIT OF PRODUCT)/S]
C  PU(K,I)           -         RATE AT WHICH PRODUCT K IS ADDED TO THE UPPER LAYER OF
C                              AN INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I
C                              = 1 (I = 2) DUE TO THE VENT FLOW COMPONENT ENTERING
C                              SPACE I = 2 (I = 1) [(UNIT OF PRODUCT)/S]
C  PVENT(K,I)        -         FLOW RATE OF PRODUCT K IN THE VENT FLOW COMPONENT
C                              ENTERING SPACE I [(UNIT OF PRODUCT)/S]
C  P(I)              -         ABSOLUTE PRESSURE IMMEDIATELY ABOVE (IN SPACE I = 1)
C                              AND BELOW (IN SPACE I = 2) THE VENT [PA = KG/(M*S**2)]
C  QL(I)             -         RATE AT WHICH ENTHALPY IS ADDED TO THE LOWER
C                              LAYER OF AN INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE
C                              SPACE I = 1 (I = 2) DUE TO THE VENT FLOW COMPONENT
C                              ENTERING SPACE I = 2 (I = 1) [W]
C  QU(I)             -         RATE AT WHICH ENTHALPY IS ADDED TO THE UPPER LAYER OF
C                              AN INSIDE ROOM I = 1 (I = 2) OR TO AN OUTSIDE SPACE I
C                              = 1 (I = 2) DUE TO THE VENT FLOW COMPONENT ENTERING
C                              SPACE I = 2 (I = 1) [W]
C  QVENT(I)          -         FLOW RATE OF ENTHALPY IN THE VENT FLOW COMPONENT
C                              ENTERING SPACE I [W]
C  T(I)              -         ABSOLUTE TEMPERATURE IMMEDIATELY ABOVE (IN SPACE I =
C                              1) AND BELOW (IN SPACE I = 2) THE VENT [K]
C  TVENT(I)          -         ABSOLUTE TEMPERATURE OF THE VENT FLOW COMPONENT
C                              ENTERING SPACE I [K]
C  DELP              -         CROSS-VENT PRESSURE DIFFERENCE, P(2) - P(1), [PA =
C                              KG/(M*S**2)]
C  DEN(I)            -         DENSITY IMMEDIATELY ABOVE (IN SPACE I = 1) AND BELOW
C                              (IN SPACE I = 2) THE VENT [KG/M**3]
C  DENVNT(I)         -         DENSITY OF THE VENT FLOW COMPONENT ENTERING SPACE I
C                              [KG/M**3]
C
C*END
C****
C**** NOTE THAT NPMAX2 SHOULD BE BIGGER THAT NPMAX
C****
      PARAMETER (NPMAX2=10)
            DIMENSION CONL(NPMAX2,2), CONU(NPMAX2,2), TL(2), TU(2)
            DIMENSION YCEIL(2), YREF(2), YLAY(2), DPREF(2)
            DIMENSION DENL(2), DENU(2)
            DIMENSION C(NPMAX2,2), CVENT(NPMAX2,2), XML(2), XMU(2)
            DIMENSION XMVENT(2)
      DIMENSION FRACM(2),FRACQ(2),FRACP(NPMAX2,2)
            DIMENSION PL(NPMAX2,2), PU(NPMAX2,2), PVENT(NPMAX2,2), P(2)
            DIMENSION QL(2),QU(2)
            DIMENSION QVENT(2), T(2), TVENT(2), DEN(2), DENVNT(2)
            DIMENSION DP(2),VB(2),VST(2), VVENT(2)
            DIMENSION DEL(2),DELY(2)
            PARAMETER (GAM=1.40D0)
            DATA IFIRST/0/
            SAVE IFIRST,GAMCUT,GAMMAX
            PARAMETER (G=9.80D0)
            PARAMETER (PI=3.141592654D0)
            PARAMETER (SIGMA2=1.045D0)
            PARAMETER (XM3=-0.7070D0)
            GR=0.D0
            APOWER=1.D0
            VHIGHFL=0.D0
            DELPFL=0.D0
```

```
      DO 5 I=1,2
      VST(I)=0.D0
      VB(I)=0.D0
      QVENT(I)=0.D0
      XMVENT(I)=0.D0
      XML(I)=0.D0
      XMU(I)=0.D0
      QL(I)=0.D0
      QU(I)=0.D0
      DO 2 NP=1,NPROD
      PVENT(NP,I)=0.D0
      PL(NP,I)=0.D0
      PU(NP,I)=0.D0
 2    CONTINUE
 5    CONTINUE
C
C***  THE FOLLOWING CODE SEGMENT COMPUTES CONSTANTS REQUIRED BY VENTCF2.
C***  IT IS EXECUTED THE FIRST TIME VENTCF IS CALLED.
C
      IF(IFIRST.EQ.0)THEN
            IFIRST = 1
            GAMCUT = (2.0D0/(GAM+1.0D0))**(GAM/(GAM-1.0D0))
            ZZZ=GAM*((2.0D0/(GAM+1.0D0))**((GAM+1.0D0)/(GAM-1.0D0)))
            GAMMAX = DSQRT(ZZZ)
      ENDIF
C
C***  IF AVENT = 0 THEN CALCULATION IS OVER
C
      IF(AVENT.EQ.0.D0)GOTO 200
C
C*** 1. CALCULATE THE P(I) AND DELP
C
      DO 10 I = 1, 2
            IF(YREF(I).LE.YVENT.AND.YVENT.LE.YLAY(I))THEN
C
C***  THE VENT IS AT OR BELOW THE REFERENCE ELEVATION IN SPACE I.  IF
C***  SPACE I IS AN INSIDE ROOM THEN BOTH THE VENT AND THE LAYER
C***  INTERFACE ARE AT THE FLOOR ELEVATION.
C
                  DP(I) = - G*DENL(I)*(YVENT - YREF(I))
            ELSE
C
C***  THE VENT IS ABOVE THE REFERENCE ELEVATION IN SPACE I.
C***  IF SPACE I IS AN INSIDE ROOM THEN THE VENT IS AT THE
C***  CEILING.
C
                  DP(I) = - G*DENL(I)*(YLAY(I)-YREF(I))
     $            - G*DENU(I)*(YVENT-YLAY(I))
            ENDIF
            P(I) = DPREF(I) + DP(I) + PDATUM
 10   CONTINUE
C
C***  DELP IS PRESSURE IMMEDIATELY BELOW THE VENT LESS PRESSURE
C***  IMMEDIATELY ABOVE THE VENT.
C
      DELP = (DPREF(2)-DPREF(1))+(DP(2)-DP(1))
C
C*** 2.  CALCULATE D, DEL(I), DELY(I) AND THE EFFECTIVE PROPERTIES OF
C***        FLOW INTO THE VENT.  IF AN ADJACENT-VENT LAYER IS "TOO THIN,"
C***        THESE ARE BASED ON MIXING OF GAS EXTRACTED FROM BOTH THE
C***        ADJACENT AND THE FAR LAYER.  CALCULATE DELDEN.
C
      D=DSQRT(4.D0*AVENT/PI)
      DO 31 I = 1, 2
            DEN(I) = 0.0D0
            T(I) = 0.0D0
            DO 22 K = 1, NPROD
                  C(K,I) = 0.0D0
 22         CONTINUE
```

```
C
C***          COMPUTE DEL(I) AND DELY(I):
C
              IF(YCEIL(I).GT.YREF(I))THEN
                        DEL(I)=MIN((YCEIL(I)-YREF(I))/2.D0,D/2.D0)
                        DELY(I)=DABS(YLAY(I)-YVENT)
              ELSE
                        DEL(I)=D/2.D0
                        DELY(I)=0.D0
              ENDIF
C
C***          COMPUTE EFFECTIVE NEAR-VENT PROPERTIES:
C
              IF(DELY(I).GT.DEL(I))THEN
                        IF(I.EQ.1)THEN
                                  DEN(1)=DENL(1)
                                  T(1)=TL(1)
                                  DO 24     K=1,NPROD
                                            C(K,1)=CONL(K,1)
24                                CONTINUE
                        ELSE
                                  DEN(2)=DENU(2)
                                  T(2)=TU(2)
                                  DO 26     K=1,NPROD
                                            C(K,2)=CONU(K,2)
26                                CONTINUE
                        ENDIF
              ELSE
                        IF(I.EQ.1)THEN
                                  DEN(1)=DENU(1)*(1.D0-((DELY(1)/DEL(1))**APOWER))
     #                                       +DENL(1)*((DELY(1)/DEL(1))**APOWER)
                                  T(1)=TU(1)*DENU(1)/DEN(1)
                                  DO 28     K=1,NPROD
                                  C(K,1)=(CONU(K,1)*DENU(1)*
     #                                       (1.D0-((DELY(1)/DEL(1))**APOWER))
     #          +CONL(K,1)*DENL(1)*((DELY(1)/DEL(1))**APOWER))/DEN(1)
28                                CONTINUE
                        ELSE
                                  DEN(2)=DENL(2)*(1.D0-((DELY(2)/DEL(2))**APOWER))
     #                                       +DENU(2)*((DELY(2)/DEL(2))**APOWER)
                                  T(2)=TL(2)*DENL(2)/DEN(2)
                                  DO 30 K=1,NPROD
                                            C(K,2)=(CONL(K,2)*DENL(2)
     #                                       *(1.D0-((DELY(2)/DEL(2))**APOWER))
     #                  +CONU(K,2)*DENU(2)*((DELY(2)/DEL(2))**APOWER))/DEN(2)
30                                CONTINUE
                        ENDIF
              ENDIF
31        CONTINUE
C
C***      DELDEN IS DENSITY IMMEDIATELY ABOVE THE VENT LESS DENSITY
C***      DENSITY IMMEDIATELY BELOW THE VENT
C
          DELDEN = DEN(1) - DEN(2)
C
C***      3. CALCULATE VST(I), THE "STANDARD" VOLUME RATE OF FLOW
C***        THROUGH THE VENT INTO SPACE I
C
C***      CALCULATE VST(I) IF DELP = 0
C
          IF(DELP.EQ.0.0D0)THEN
                    VST(1) = 0.0D0
                    VST(2) = 0.0D0
          ENDIF
          IF(DELP.EQ.0.D0)     GOTO 32
C
C***      CALCULATE VST(I) FOR NONZERO DELP
C
          IF(DELP.GT.0.0D0)THEN
```

```
                VST(2) = 0.0D0
                RHO = DEN(2)
                EPS = DELP/P(2)
        ENDIF
        IF(DELP.LT.0.0D0)THEN
                VST(1) = 0.0D0
                RHO = DEN(1)
                EPS = -DELP/P(1)
        ENDIF
        X = 1.0D0 - EPS
        COEF = 0.60D0 + 0.25D0*EPS
        XO = 1.0D0
        EPSCUT = EPSP*MAX(XO,DPREF(1),DPREF(2))
        EPSCUT = DSQRT(EPSCUT)
        SRDELP = DSQRT(DABS(DELP))
        FNOISE = 1.0D0
        IF((SRDELP/EPSCUT).LE.130.D0)THEN
                FNOISE = 1.0D0 - DEXP(-SRDELP/EPSCUT)
C
C***    NOTE: IF SINGLE PRECISION THEN USED 65. INSTEAD OF 130.
C
        ENDIF
        IF(EPS.LE.0.1D-5)THEN
                W = 1.0D0 - 0.75D0*EPS/GAM
        ELSE
                IF(EPS.LT.GAMCUT)THEN
                        GG = X**(1.0D0/GAM)
                        FF = DSQRT((2.0D0*GAM/(GAM-1.0D0))*GG*GG*
     $                                                  (1.0D0-X/GG))
                ELSE
                        FF = GAMMAX
                ENDIF
                        W = FF/DSQRT(EPS+EPS)
        ENDIF
        V = FNOISE*COEF*W*DSQRT(2.0D0/RHO)*AVENT*SRDELP
        IF(DELP.GT.0.0D0)VST(1) = V
        IF(DELP.LT.0.0D0)VST(2) = V
   32 CONTINUE
C
C***    4. WHEN CROSS-VENT DENSITY CONFIGURATION IS UNSTABLE, I.E.,
C***           DELDEN > 0, THEN CALCULATE THE VENT FLOW ACCORDING TO:
C***           COOPER, L.Y., COMBINED PRESSURE- AND BUOYANCY-DRIVEN FLOW
C***           THROUGH A HORIZONTAL VENT, TO APPEAR AS NISTIR, NATIONAL
C***           INSTITUTE OF STANDARDS AND TECHNOLOGY, GAITHERSBURG MD
C
C***    FOR STABLE CONFIGURATION, GO TO 5. AND VOLUME FLOW RATES WITH
C***    STANDARD MODEL
C
        IF(DELDEN.LE.0.0D0) GOTO 35
C
C***    FOR UNSTABLE CONFIGURATION, NOW CALCULATE THE COMBINED PRESSURE-
C***    AND BUOYANCY-DRIVEN VOLUME VENT FLOW RATES        FROM THE HIGH-TO-LOW
C***    AND       FROM THE LOW-TO-HIGH SIDES OF THE VENT, VBHIGH AND VBLOW,
C***    RESPECTIVELY. FROM THESE THEN CALCULATE THE COMBINED PRESSURE-
C***    AND BUOYANCY-DRIVEN VOLUME FLOW RATES, VB(I), THROUGH THE VENT
C***    INTO SPACE I.
C
        TBAR=(T(1)+T(2))/2.D0
        DENBAR=(DEN(1)+DEN(2))/2.D0
        XMEW=(0.04128D-7)*DENBAR*(TBAR**2.5D0)/(TBAR+110.4D0)
        EPSDEN=DELDEN/DENBAR
        GR=2.D0*G*(D**3)*EPSDEN/((XMEW/DENBAR)**2.D0)
        IF(DELP.GT.0.D0) EPSDEN=-EPSDEN
        VHIGHFL=0.1754D0*AVENT*DSQRT(2.D0*G*D*DABS(EPSDEN))*
     1                                          DEXP(0.5536D0*EPSDEN)
        DELPFL=0.2427D0*(4.D0*G*DABS(EPSDEN*DENBAR)*D)*(1.D0+EPSDEN/2.D0)*
     1                                          DEXP(1.1072D0*EPSDEN)
        DPDDPFL=DABS(DELP)/DELPFL
        SIGMA1=FNOISE*COEF*W/0.1780D0
```

```
      IF(DPDDPFL.GE.1.D0)THEN
             VBLOW=0.D0
             VBHIGH=VHIGHFL*(1.D0-(SIGMA2**2.D0)+
1                   DSQRT(SIGMA2**4.D0+(SIGMA1**2.D0)* (DPDDPFL-1.D0)))
      ELSE
             VEXMAX=0.055D0*(4.D0/PI)*AVENT*DSQRT(G*D*DABS(EPSDEN))
             XM=(SIGMA1/SIGMA2)**2.D0-1.D0
             VBLOW=VEXMAX*(((1.D0+XM3/2.D0)*((1.D0-DPDDPFL)**2)-
1                                        (2.D0+XM3/2.D0)*(1.D0-DPDDPFL))**2.D0)
             IF(DPDDPFL.EQ.0.D0)THEN
                    VBHIGH=VBLOW
             ELSE
                    VBHIGH=VBLOW+
1            (XM-DSQRT(1.D0+(XM**2.D0-1.D0)*(1.D0-DPDDPFL)))*
1     VHIGHFL/(XM-1.D0)
             ENDIF
      ENDIF
      IF(DELP.GT.0.D0)THEN
             VB(1)=VBHIGH
             VB(2)=VBLOW
      ELSE
             VB(1)=VBLOW
             VB(2)=VBHIGH
      ENDIF
C
C***  5. CALCULATE VVENT(I), THE VOLUME RATE OF FLOW THROUGH
C***  THE VENT INTO SPACE I
C
35    CONTINUE
      IF(DELDEN.LE.0.0D0)THEN
             VVENT(1) = VST(1)
             VVENT(2) = VST(2)
      ELSE
             IF((0.D0.LT.GR).AND.(GR.LT.2.D7))THEN
             VVENT(1)=VST(1)+(GR/2.D7)*(VB(1)-VST(1))
             VVENT(2)=VST(2)+(GR/2.D7)*(VB(2)-VST(2))
                    ELSE
                    VVENT(1)=VB(1)
                    VVENT(2)=VB(2)
             ENDIF
      ENDIF
C***  6. CALCULATE THE VENT FLOW PROPERTIES
C
      DENVNT(1) = DEN(2)*P(1)/P(2)
      DENVNT(2) = DEN(1)*P(2)/P(1)
      TVENT(1) = T(2)
      TVENT(2) = T(1)
      DO 50 K = 1, NPROD
             CVENT(K,1) = C(K,2)
             CVENT(K,2) = C(K,1)
50    CONTINUE
C
C***  7. CALCULATE THE VENT MASS FLOW RATES
C
      DO 60 I = 1,2
             XMVENT(I) = DENVNT(I)*VVENT(I)
60    CONTINUE
C
C***  8. CALCULATE THE REST OF THE VENT FLOW RATES
C
      DO 70 I=1,2
             QVENT(I) = XMVENT(I)*CP*TVENT(I)
             DO 65 K = 1, NPROD
                    PVENT(K,I) = XMVENT(I)*CVENT(K,I)
65           CONTINUE
70    CONTINUE
C
C***  9. CALCULATE THE RATE AT WHICH THE VENT FLOWS ADD MASS,
```

```
C***    ENTHALPY, AND PRODUCTS TO THE LAYERS OF THE SPACES FROM
C***    WHICH THEY ARE EXTRACTED. FIRST TREAT LAYERS OF SPACE 1
C***    AND THEN SPACE 2.
C
        DO 150 I = 1,2
                FRACM(I)=1.D0
                FRACQ(I)=1.D0
                DO 72 K=1,NPROD
                        FRACP(K,I)=1.D0
72              CONTINUE
                IF(DELY(I).GT.DEL(I))THEN
                        IF(I.EQ.1)THEN
                        XML(1)=-XMVENT(2)
                                XMU(1)=0.0D0
                                QL(1) = -QVENT(2)
                                QU(1) = 0.0D0
                                DO 75 K=1,NPROD
                                        PL(K,1) = -PVENT(K,2)
                                        PU(K,1) = 0.0D0
75                              CONTINUE
                                IF(YCEIL(1).EQ.YREF(1))THEN
                                        XMU(1)=XML(1)
                                        QU(1)=QL(1)
                                        DO      80 K=1,NPROD
                                                PU(K,1)=PL(K,1)
80                                      CONTINUE
                                ENDIF
                        ELSE
                                XMU(2)=-XMVENT(1)
                                XML(2)=0.D0
                                QU(2)=-QVENT(1)
                                QL(2)=0.D0
                                DO 85 K=1,NPROD
                                        PU(K,2)=-PVENT(K,1)
                                        PL(K,2)=0.D0
85                              CONTINUE
                                IF(YCEIL(2).EQ.YREF(2))THEN
                                        XML(2)=XMU(2)
                                        QL(2)=QU(2)
                                        DO 90 K=1,NPROD
                                                PL(K,2)=PU(K,2)
90                                      CONTINUE
                                ENDIF
                        ENDIF
                ELSE
                        IF(I.EQ.1)THEN
                                XMU(1)=-DENU(1)*(1.D0-((DELY(1)/DEL(1))**APOWER))
     #
                                        *VVENT(2)
                                XML(1)=-DENL(1)*(((DELY(1)/DEL(1))**APOWER))*VVENT(2)
                                IF(XMVENT(2).GT.0.D0)FRACM(2)=XML(1)/XMVENT(2)
                                QU(1)=XMU(1)*CP*TU(1)
                                QL(1)=XML(1)*CP*TL(1)
                                IF(QVENT(2).GT.0.D0)FRACQ(2)=QL(1)/QVENT(2)
                                DO 95 K=1,NPROD
                                        PU(K,1)=XMU(1)*CONU(K,1)
                                        PL(K,1)=XML(1)*CONL(K,1)
                                        IF(PVENT(K,2).GT.0.D0)FRACP(K,2)=PL(K,1)/PVENT(K,2)
95                              CONTINUE
                                IF(YCEIL(1).EQ.YREF(1))THEN
                                        XML(1)=XMU(1)
                                        QL(1)=QU(1)
                                        DO 100 K=1,NPROD
                                                PL(K,1)=PU(K,1)
100                                     CONTINUE
                                ENDIF
                        ELSE
                                XML(2)=-DENL(2)*(1.D0-((DELY(2)/DEL(2))**APOWER))
```

```
#                                           *VVENT(1)
                                    XMU(2)=-DENU(2)*(((DELY(2)/DEL(2))**APOWER))*VVENT(1)
                                    IF(XMVENT(1).GT.0.D0)FRACM(1)=XMU(2)/XMVENT(1)
                                    QL(2)=XML(2)*CP*TL(2)
                                    QU(2)=XMU(2)*CP*TU(2)
                                    IF(QVENT(1).GT.0.D0)FRACQ(1)=QU(2)/QVENT(1)
                                    DO 105 K=1,NPROD
                                          PL(K,2)=XML(2)*CONL(K,2)
                                          PU(K,2)=XMU(2)*CONU(K,2)
                                          IF(PVENT(K,1).GT.0.D0)FRACP(K,1)=PU(K,2)/PVENT(K,1)
105                                 CONTINUE
                                    IF(YCEIL(2).EQ.YREF(2))THEN
                                          XMU(2)=XML(2)
                                          QU(2)=QL(2)
                                          DO 110 K=1,NPROD
                                                PU(K,2)=PL(K,2)
110                                       CONTINUE
                                    ENDIF
                              ENDIF
                        ENDIF
150         CONTINUE
200   CONTINUE
            RETURN
            END
```

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An algorithm and associated FORTRAN 77 subroutine, called *VENTCF2*, is presented for calculating the effects on two-layer compartment fire environments of the quasi-steady flow through a circular, shallow (i.e., small ratio of depth to diameter), horizontal vent connecting two spaces. The two spaces can be either two inside rooms of a multi-room facility or one inside room and the outside ambient environment local to the vent. The description of the flow through the vent is determined by combining considerations of the uni-directional-type of flow driven by a cross-vent pressure difference and, when appropriate, the combined pressure- and buoyancy-driven flows which occur when the density configuration across the vent is unstable, i.e., a relatively cool, dense gas in the upper space overlays a less dense gas in the lower space. In the algorithm, calculation of the rates of flow exchange between the two spaces is based on previously reported model equations. Characteristics of the geometry and the instantaneous environments of the two spaces are assumed to be known and specified as inputs. The outputs calculated by the algorithm/subroutine are the rates and the properties of the vent flow at the elevation of the vent as it enters the top space from the bottom space and/or as it enters the bottom space from the top space. Rates of mass, enthalpy, and products of combustion extracted by the vent flows from upper and lower layers of inside room environments and from outside ambient spaces are determined explicitly. The algorithm/subroutine is an advanced version of the algorithm/subroutine *VENTCF*. The subroutine is completely modular, and it is suitable for general use in two-layer, multi-room, zone-type fire model computer codes. It has been tested over a wide range of input variables and these tests are described.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)

building fires; compartment fires; computer models; fire models; mathematical models; vents; zone models

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